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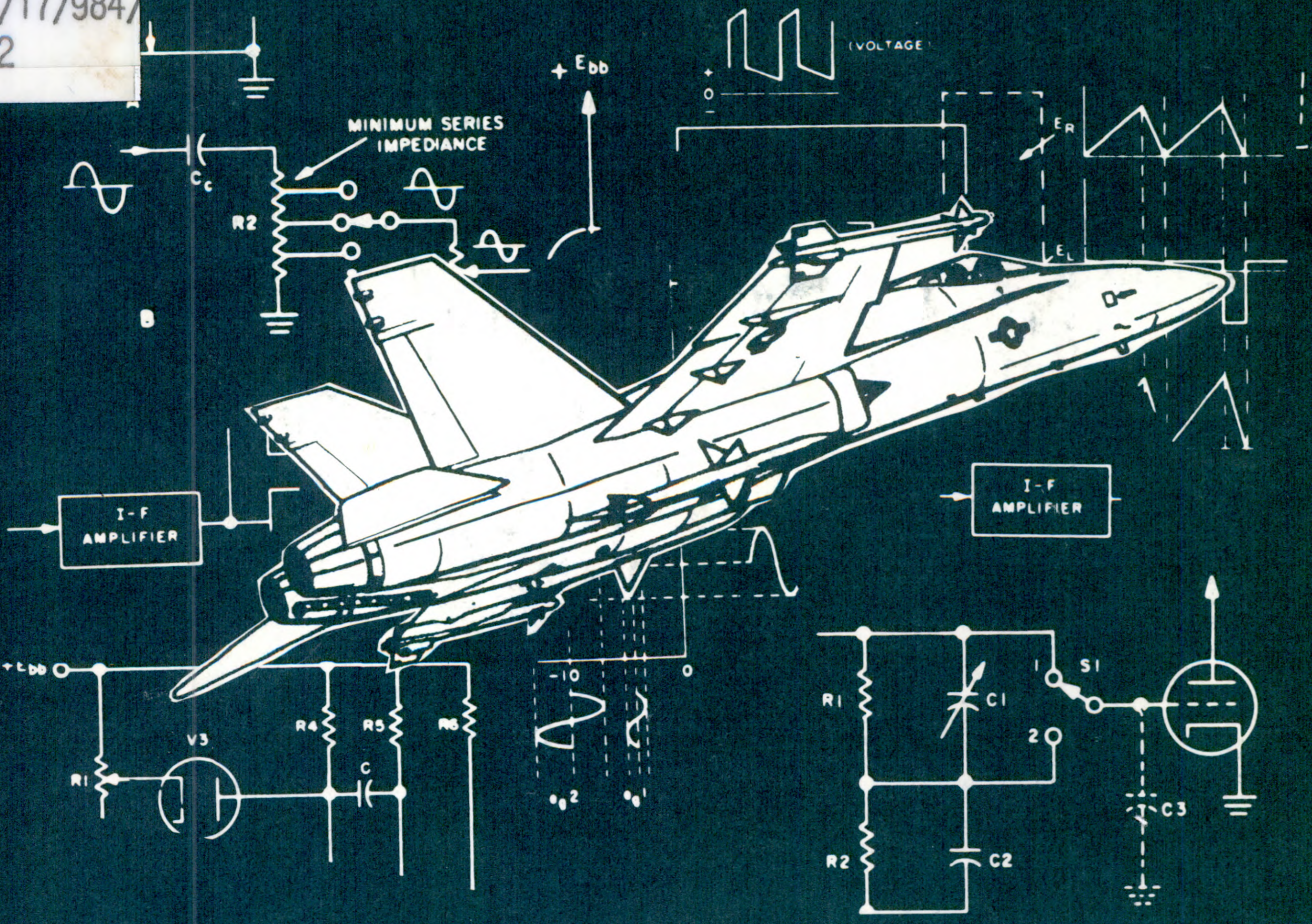

AVIATION

ELECTRONICS TECHNICIAN 3 & 2, PART 2

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NAVAL EDUCATION AND TRAINING COMMAND
RATE TRAINING MANUAL AND NONRESIDENT CAREER COURSE

NAVEDTRA 10317-F

material i

Although the words "he," "him," and "his" are used sparingly in this manual to enhance communication, they are not intended to be gender driven nor to affront or discriminate against anyone reading *Aviation Electronics Technician 3 & 2,* Part 2, NAVEDTRA 10317-F.

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AVIATION ELECTRONICS TECHNICAN 3 & 2, PART 2

NAVEDTRA 10317-F

DEPARTMENT OF THE NAVY ★ CHIEF OF NAVAL EDUC AND TNG ★

1984 Edition Prepared by
AVCM Marvin S. Baker

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PREFACE

This Rate Training Manual and Nonresident Career Course (RTM/NRCC), *Aviation Electronics Technician 3 & 2*, Part 2, NAVEDTRA 10317-F, follows *Avionics Technician (AQ/AT/AX) 3 & 2*, Part 1, NAVEDTRA 10319 and is intended to provide enlisted personnel with information pertinent to their assignments and necessary for advancement to the Aviation Electronics Technician 3 & 2 rates. This includes information on airborne communication, navigation, and ECM equipment, radar, IFF, ground support equipment, reflectometer testers, and magnetic recorders.

Designed for individual study instead of formal classroom instruction, the RTM provides subject matter that relates directly to the Occupational Standards of the AT 3 & 2 rates. The NRCC provides the usual way of satisfying the requirements for completing the RTM. It consists of a set of assignments which include learning objectives and supporting questions designed to help students study the RTM. You may find it beneficial to read through the entire training package and to read the front matter of the NRCC before you begin serious study.

This training manual and nonresident career course was prepared by the Naval Education and Training Program Development Center, Pensacola, Florida, for the Chief of Naval Education and Training. Special credit is given to the following for assistance during the preparation of the manual: Chief of Naval Technical Training, NAS Memphis, Millington, Tennessee; the Naval Aviation Logistics Center, Patuxent River, Maryland; Naval Air Technical Training Center, NAS Memphis, Millington, Tennessee; Naval Air Maintenance Training Detachment 1001, NAS Whidbey Island, Oak Harbor, Washington; NAMTD 1008, NAS Miramar, San Diego, California; NAMTD 1034, Cecil Field, Jacksonville, Florida; and the AIMD, NAS Whidbey Island, Oak Harbor, Washington.

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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INTRODUCTION

AVIATION ELECTRONICS TECHNICIAN 3 & 2, PART 2

This rate training manual has been prepared for men and women of the Navy, and of the Naval Reserve who are studying for advancement in the Aviation Electronics Technician rating. Before you study this manual, you should complete *Avionics Technician (AQ/AT/AX) 3 & 2*, Part 1, NAVEDTRA 10319. As part of a series of training manuals, these manuals are designed to give you background information necessary for the proper performance of your duties at the third and second class levels. The manual is based on the professional qualifications for AT 3 & 2, as listed in the *Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards*, NAVPERS 18068 (current edition). (The Occupational Standards which were current at the time this book was written are included in this introduction. For those standards which are addressed in this book we have indicated the number of the chapter in which they were addressed.)

The requirements for advancement in rating are discussed in *Military Requirements for Petty Officer Third Class*, NAVEDTRA 10044 series. (When you are studying for advancement, always make sure you have the latest edition of the *Bibliography for Advancement Examination Study*, NAVEDTRA 10052.) You should also check with the educational services office of your command for possible changes to the requirements listed in the manual.

AVIATION ELECTRONICS TECHNICIAN

The following three ratings are separate until the E-9 level at which time they, with the AE rating, compress to form the avionics rating.

AT (Aviation Electronics Technician)

AQ (Aviation Fire Control Technician)

AX (Aviation Antisubmarine Warfare Technician)

Specialty groups within these ratings have been assigned Navy Enlisted Classification (NEC) codes. The NEC codes reflect special knowledge and skills of personnel.

Normally, you will be assigned duty according to your NEC code. As an AT, your assigned billet will probably call for an equipment specialist. This, however, does not relieve you of the need to acquire overall knowledge of the avionics rating, as such knowledge will be helpful to you in your job and will be necessary for you to advance in your career.

AVIATION ELECTRONICS TECHNICIAN, 3 & 2 OCCUPATIONAL STANDARDS

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14800	ASSIST IN TROUBLESHOOTING AND REPAIR OF RADAR SYSTEMS	3
14801	ASSIST IN TROUBLESHOOTING AND REPAIR OF RADAR AND TACTICAL DISPLAYS	3
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14804	ASSIST IN TROUBLESHOOTING AND REPAIR OF DOPPLER NAVIGATION EQUIPMENT	2
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NUMBER	OCCUPATIONAL STANDARD	CHAPTER
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14809	ASSIST IN TROUBLESHOOTING AND REPAIR OF INFRARED DEVICES	
14810	ASSIST IN TROUBLESHOOTING AND REPAIR OF RECORDER SYSTEMS	7
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14968	ASSIST IN TROUBLESHOOTING AND REPAIR OF AIRCRAFT DIGITAL DATA SYSTEMS	
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28375	USE MAINTENANCE AND SERVICE INSTRUCTIONS TO MAINTAIN AVIONICS SYSTEMS	
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38943	ASSIST IN MAINTAINING THE FOLLOWING: A. TECHNICAL LIBRARY B. TOOL INVENTORY C. TRAINING RECORDS D. TEST EQUIPMENT INVENTORY	
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CHAPTER 1

AIRBORNE COMMUNICATIONS EQUIPMENT

(NOTE: You should be familiar with the information contained in NAVEDTRA 10319 *Avionics Technician 3 & 2*, Part I prior to reading this RTM.)

COMMUNICATIONS RECEIVERS AND TRANSMITTERS

As an aviation electronics technician, you will be tasked to operate and maintain many different types of aircraft communications equipment. These equipments differ in many respects; however, in other respects they are similar. As an example, there are various models of AM radios, yet they all serve the same function and operate on the same basic principles. It is beyond the scope of this manual to present information that relates to all of the many different equipments; therefore only representative equipment will be discussed, to give you the basic capabilities and principles of operation of the various types of communication equipment.

Distinctive features of naval airborne communications equipment include automatic tuning, subassembly and modular types of construction, shock mounting of major units, and pressurized cases, as well as the electronic components and circuitry employed.

Automatic tuning, which makes possible rapid selection of preset channels, is used in most modern airborne communications equipment. This feature is essential because frequency changes must be made accurately and quickly. Since an automatic tuning system provides great simplicity of control for the operator, the entire operation is usually accomplished by means of a single dial.

Shock mounting is required because of vibration and the extreme forces present in normal aircraft operation.

The utilization of subassembly and modular construction in electronic equipment simplifies maintenance and repair. It permits the removal and replacement of sections containing defective parts without dismantling entire equipment.

All radio communications equipment, whether military or civilian, is designed to operate within certain well-defined frequency limits. In this chapter the terms used in reference to frequency bands designate major portions of the radio frequency spectrum. (See table 1-1.) The designations and abbreviations are those in general use.

GENERAL PURPOSE RECEIVER

A typical general purpose receiver consisting of a receiver and its mounting is a superheterodyne receiver, capable of receiving RF signals from 190 kHz to 550 kHz and from 2 MHz to 25 MHz, covered in five frequency bands. A mechanical type counter, located on the front panel of the receiver (see fig. 1-1), indicates the frequency (in MHz) of received signals. It can receive signals which are of the audio modulated (AM), unmodulated continuous wave (CW), or frequency shift keyed (FSK) types. Accurate frequency calibration of the receiver is obtained through a built-in circuit consisting of a 500-kHz crystal-controlled oscillator and a multivibrator.

The maintenance instruction manual for the receiver presents, in detail, the theory and operation of the receiver, the maintenance, tests, alignment procedures, specifications, and a complete list of test equipment required. Only a brief summary of the theory of operation of a typical receiver is presented in this chapter. Keep

Table 1-1.—Radiofrequency classifications

Band	Frequency spectrum (kHz)	Wavelength in meters
VLF (Very Low)	10– 30	30,000–10,000
LF (Low)	30– 300	10,000– 1,000
MF (Medium)	300– 3,000	1,000– 100
HF (High)	3,000– 30,000	100– 10
VHF (Very High)	30,000– 300,000	10–1
UHF (Ultrahigh)	300,000– 3,000,000	1–0.1
SHF (Superhigh)	3,000,000– 30,000,000	0.1–0.01
EHF (Extremely High)	30,000,000–300,000,000	0.01–0.001

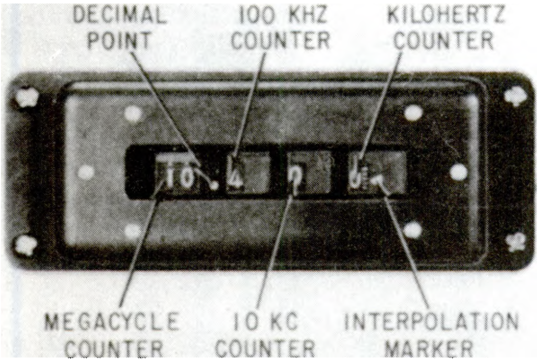

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Figure 1-1.—Megahertz Frequency Indicator.

in mind that various receivers may have slightly different circuitry and controls, but they all work on the same basic principles.

Theory of Operation

A typical receiver employs double conversion; that is, all received RF signals are first converted to variable intermediate frequency (IF), amplified, and converted again, to a fixed IF. Two of the benefits obtained by double conversion are high gain and sensitivity.

For CW reception, the set employs a beat frequency oscillator (BFO), with a control for variable pitch or tone. A CW signal, as you know, contains no modulation; so a separate oscillator must be built into the receiver to beat

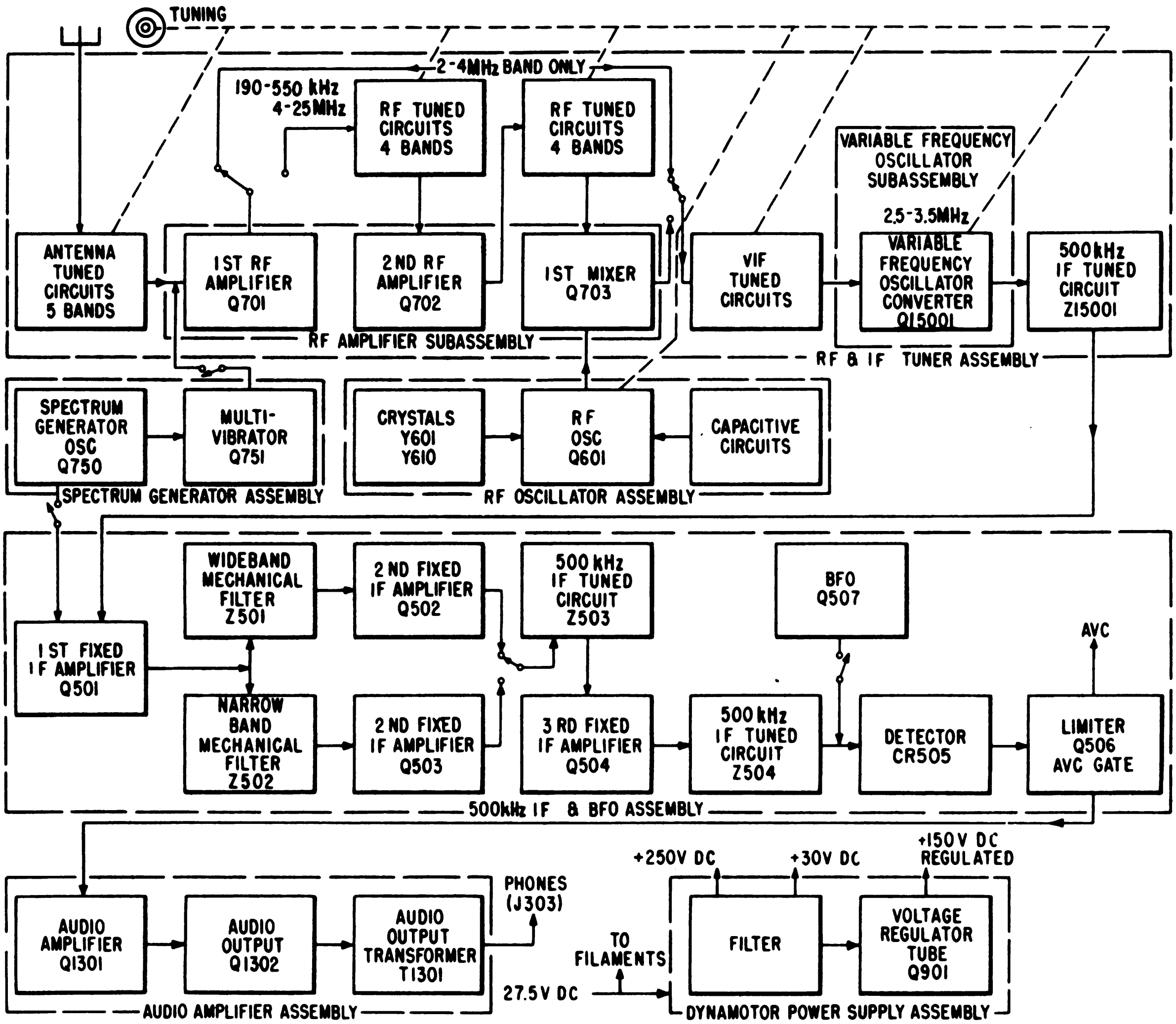
TUNING
2-4MHz BAND ONLY
190-550 kHz
4-25MHz
RF TUNED CIRCUITS 4 BANDS
RF TUNED CIRCUITS 4 BANDS
VARIABLE FREQUENCY OSCILLATOR SUBASSEMBLY
2.5-3.5MHz
ANTENNA TUNED CIRCUITS 5 BANDS
1ST RF AMPLIFIER Q701
2ND RF AMPLIFIER Q702
1ST MIXER Q703
VIF TUNED CIRCUITS
VARIABLE FREQUENCY OSCILLATOR CONVERTER Q15001
500kHz IF TUNED CIRCUIT Z15001
RF AMPLIFIER SUBASSEMBLY
RF & IF TUNER ASSEMBLY
SPECTRUM GENERATOR OSC Q750
MULTI-VIBRATOR Q751
SPECTRUM GENERATOR ASSEMBLY
CRYSTALS Y601 Y610
RF OSC Q601
CAPACITIVE CIRCUITS
RF OSCILLATOR ASSEMBLY
WIDEBAND MECHANICAL FILTER Z501
2 ND FIXED IF AMPLIFIER Q502
500 kHz IF TUNED CIRCUIT Z503
BFO Q507
AVC
1 ST FIXED IF AMPLIFIER Q501
NARROW BAND MECHANICAL FILTER Z502
2 ND FIXED IF AMPLIFIER Q503
3 RD FIXED IF AMPLIFIER Q504
500 kHz IF TUNED CIRCUIT Z504
DETECTOR CR505
LIMITER Q506 AVC GATE
500kHz IF & BFO ASSEMBLY
+250V DC
+30V DC
+150V DC REGULATED
PHONES (J303)
AUDIO AMPLIFIER Q1301
AUDIO OUTPUT Q1302
AUDIO OUTPUT TRANSFORMER T1301
TO FILAMENTS
FILTER
VOLTAGE REGULATOR TUBE Q901
27.5V DC
AUDIO AMPLIFIER ASSEMBLY
DYNAMOTOR POWER SUPPLY ASSEMBLY

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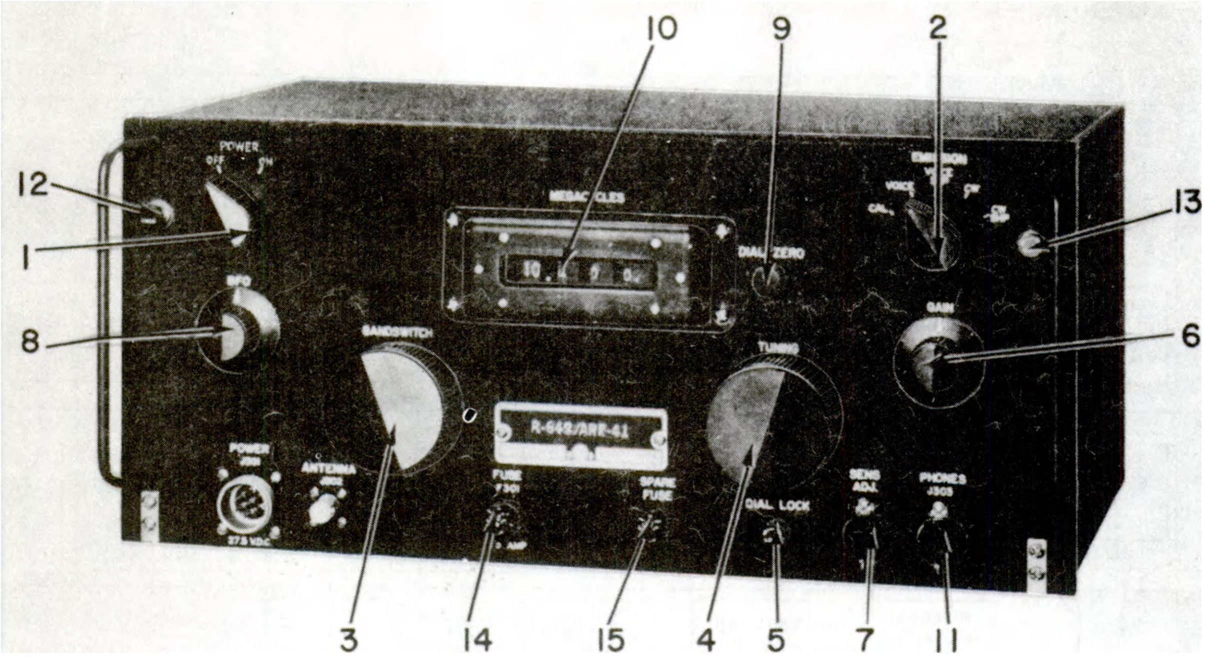
Figure 1-2.—Block diagram of a typical general purpose receiver.

(mix) with the incoming IF to produce a signal that, when detected and amplified, can be heard within the audio range.

Figure 1-2 is a block diagram of a typical receiver. If you refer to this diagram as you read the following discussion, you will find the explanation of the receiver's operation easier to understand.

The incoming RF signal is received by the antenna (normally a long-wire antenna is utilized) and applied to one of five tuned circuits, depending upon the frequency band selected. The signal is then applied to the base of Q701, the 1st RF amplifier, for amplification. After the first stage of RF amplification, frequencies within the range of bands 1, 3, 4 and 5 (190-550 kHz and 4-25 MHz) are applied through tuned circuits to the second RF amplifier Q702, and then through more tuned circuits to the first mixer Q703. The function of Q703 is to heterodyne the output of the RF oscillator Q601, with the incoming RF, and produce a variable IF of 2-4 MHz. Band 2 frequencies of this receiver are 2-4 MHz without heterodyning and therefore



	CONTROL		FUNCTION
1.	POWER		Primary power off-on control.
2.	EMISSION	(CAL)	Connects frequency calibration circuitry.
		(VOICE)	Connects broad-band (9.4 kilocycle) filter for radiotelephone reception.
		(VOICE SHP)	Connects narrow-band (1.4 kilocycle) filter for radiotelephone reception.
		(CW)	Connects broad-band (6.0 kilocycle) filter for cw reception.
		(CW SHP)	Connects narrow-band (1.4 kilocycle) filter for cw reception.
3.	BANDSWITCH		Selects frequency of reception in one-megacycle steps.
4.	TUNING		Tunes the R-648/ARR-41 throughout a one-megacycle increment.
5.	DIAL LOCK		Locks the TUNING control at a desired setting.
6.	GAIN		Controls sensitivity.
7.	SENS ADJ.		Vernier sensitivity adjustment.
8.	BFO		Controls tone of beat signal during cw reception.
9.	DIAL ZERO		Sets MEGACYCLES frequency indicator for calibration.
10.	MEGACYCLES		Indicates frequency in megacycles.
11.	PHONES		Connector for H-1/AR or H-4/AR Headset.
12, 13.	LOCK		Locks the front panel to the chassis.
14.	FUSE F301		Five ampere overload protection fuse.
15.	SPARE FUSE		Spare fuse, replaces item 14.
16.	AUDIO GAIN		A preinstallation adjustment used to set the audio output to the desired level.

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Figure 1-3.—Typical general purpose receiver.

are switched around the 2nd RF amplifier and 1st mixer circuits. (NOTE: The switches in figure 1-2 are shown in the band 2 position.)

At this point, any incoming signal, regardless of the original frequency, is within the frequency range of 2-4 MHz, and is applied through the variable IF (VIF) tuned circuits to the variable frequency oscillator converter Q15001. (NOTE: The broken lines in fig. 1-2 indicate the various circuits which are tuned together by the frequency controls on the front of the set.) (See fig. 1-3.) Mixer Q15001 heterodynes the variable 2-4 MHz IF signal with a locally generated 2.5-MHz to 3.5-MHz signal, producing an output of 500 kHz, the fixed IF.

The 500-kHz IF signal is then applied to the base of Q501 for the first IF amplification. The output of Q501 passes through either a broad or narrow band mechanical filter depending on the setting of the emission switch (fig. 1-3) to either Q502 or Q503 second IF amplifiers. The output of the second IF amplifier is then applied through a tuned circuit to the base of the third IF amplifier Q504, the collector of which contains the IF tuned circuit Z504. Tuned circuit Z504 couples the output of Q504 to the diode detector CR505. The function of CR505 is to recover the modulation component of the received RF signal (detection). The BFO may be switched into CR505 input by operation of the emission switch to the CW or CW SHP (CW sharp) positions. In this manner a beat note is produced with the 500-kHz IF signal, which is a variable tone to be used with CW reception. Output of the detector CR505 is applied to Q506, the limiter and automatic volume control (AVC) gate. One half of the duodiode Q506 functions as an AVC gate control and prevents application of AVC voltage (a negative voltage proportional to the carrier level provided by CR505 output) to the various amplifiers until full receiver sensitivity has been reached. The other half of Q506 is a noise limiter, which suppresses undesired noise pulses. The output of Q506 is an audio voltage proportional to the modulation signal component of the received RF signal. Audio amplifiers Q1301 and Q1302 serve to amplify the audio signal. The output of Q1302 is applied to the audio output transformer T1301, the output of which goes to J303, a headset phone jack located on the front of the receiver. (See fig. 1-3.)

The spectrum generator assembly, consisting of a crystal-controlled oscillator Q750, and a multivibrator divider circuit Q751, is used to calibrate the frequency indicator dial. (See fig. 1-3.) When the emission switch is placed in the CAL position, the following occurs: the crystal-controlled oscillator Q750 produces an accurate 500-kHz signal. This signal is applied to the base of the first IF amplifier Q501 and to one base and one collector of the multivibrator divider, Q751. The multivibrator fires on every fifth pulse and produces an output to the first RF amplifier Q701, of 100 kHz. This 100-kHz signal is rich in harmonics and allows the RF tuned circuits to tune to a particular harmonic, depending upon the resonant frequency to which they are set. For example, let's assume the receiver is set to 3 MHz on the frequency counter dial. If the receiver tuned circuits were not exactly tuned to 3 MHz, a tone (signal) would pass through the first IF amplifier Q501, and be heard in the headset. By fine tuning the receiver's frequency dial, a beat note (silence) can be heard (due to heterodyning the 500-kHz signal applied to Q501 and the selected harmonic of the 100-kHz from the multivibrator). When the beat note is heard, all circuits of the receiver are exactly tuned to 3 MHz. Should the frequency indicator not read 3 MHz, it can be set to 3 MHz by the DIAL ZERO knob.

HF TRANSCEIVER

There are numerous models of HF transceivers used throughout the Navy. Even though there are newer models, we will discuss the AN/ARC-94, because it is representative in theory of most models you will encounter.

Radio Set AN/ARC-94 provides facilities for communication between aircraft, and between aircraft and fixed or mobile ground communications stations. The AN/ARC-94 transmits and receives communications in the high-frequency (HF) band and can operate on a frequency range from 2.0 to 29.999 MHz. The set includes Radio Receiver-Transmitter RT-648/ARC-94, Radio Set Control C-3940/ARC-94, and Mounting

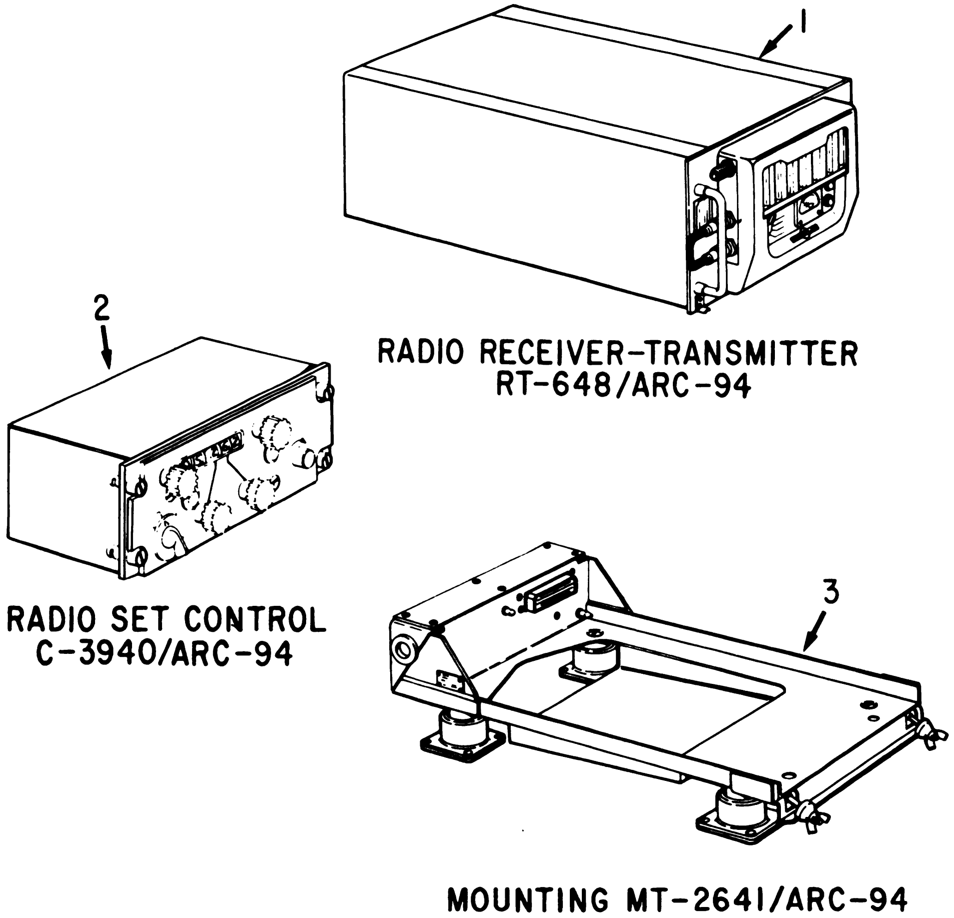

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Figure 1-4.—ARC-94 components.

MT-2641/ARC-94. (See fig. 1-4.) The receiver-transmitter (RT) unit is of modular construction for ease of maintenance. In addition to the set components, the complete aircraft installation requires a headset, microphone, key, antenna coupler, and antenna.

The RT unit functions as a part of an overall HF communications system. Frequency selection is in increments of 1 kHz over the entire band, providing a choice of 28,000 operating frequencies.

The control unit (fig. 1-4) provides for remote selection of operating frequency, and for selection of upper sideband (USB), lower sideband (LSB), amplitude modulation (AM), data link, or CW mode of operation.

The mounting provides for mechanical support, electrical connection, and isolation from airframe vibration and shocks.

Operation of the set, as discussed briefly in the following paragraphs, is divided into a transmit function, a receive function, and a carrier generator function which is common to both reception and transmission. The brief discussion is in block diagram form. (Refer to fig. 1-5 in connection with the discussion.) Principal intelligence signal flow is indicated by heavy lines.

The diagram is divided functionally rather than by the physical location of the parts. Blocks and individual component parts mentioned in the discussion are referenced in the standard manner for modular construction. Modules are referenced as A1, A2, and so on. Where detail parts are considered in a discussion, the module designation and the part designation are combined into a compound reference, such as A1R2, A2R2, and so on, to indicate the module and specific part. Parts located on submodules are designated by a triple compound designation such as A12A2C3, where A12 is the module, A2 is the submodule, and C3 is the detail part of interest.

Transmit Function

The transmit function includes an AF input section, an IF translator section, an RF translator section, and a power amplifier section.

The AF input section provides coupling and amplification for the voice intelligence to be transmitted. The IF translator section contains the circuitry for selecting the desired mode of operation and the stages that modulate and process the desired signal accordingly. The RF translator section performs the final conversion step in translating the modulated signal information to the frequency band selected for transmission. The carrier generator function provides all the frequencies required for the double conversion transmit function. The carrier generator function also provides all the frequencies required for demodulating in the receive function. Tuning is carried out within the carrier generator function by means of an electromechanical autopositioner system.

AF INPUT SECTION.—An audio signal from the operator's microphone, fed into the 100-ohm, unbalanced input, is amplified in audio amplifier stages A9Q1 and A9Q2 and applied to the balanced modulator in the IF translator section.

When a 600-ohm balanced audio input is used, the signal is preamplified by audio amplifier A9Q8 before being applied to A9Q1 and A9Q2.

When the transmitter is operating in the CW mode, a 1-kHz audio signal is obtained from frequency divider module A1. This 1-kHz signal is then fed from CW keying relay A9K1 to the audio input.

IF TRANSLATOR SECTION.—The audio signal from the AF input section and a carrier signal from locked oscillators A2Q4 and A2Q8 in the carrier generator function are combined in the balanced modulator. The balanced modulator yields a suppressed carrier amplitude modulated output consisting of upper and lower sidebands. The balanced modulator output is fed to automatic load control A3Q1, which is controlled by a signal fed back from the power amplifier in the power amplifier section. The output level of the automatic load control stage is adjusted by the feedback voltage to maintain the transmitter output at a predetermined level. From A3Q1, the signal is applied to A3Q2 through relay A3K5 (relay not shown). The desired signal is then amplified by IF amplifier A3Q2 and applied to the mode selector.

The mode selector provides the option of operating in either SSB, AM, DATA, or CW mode. In SSB mode, the further option of using upper sideband (USB) or lower sideband (LSB) is provided.

In AM mode, the double-sideband suppressed carrier signal is applied to 3-kHz mechanical filter A3FL1, which passes only the upper sideband. A 500-kHz carrier signal from the carrier generator function is reinserted into the upper sideband at the output of filter A3FL1.

In SSB mode, the carrier reinsertion capability is disabled. The double-sideband suppressed carrier output of A3Q2 is switched to a 3-kHz mechanical filter, either A3FL1 or A3FL2, depending on the setting of the mode selector. Filter A3FL1 passes only the USB and A3FL2 passes only the LSB. The sideband not passed is suppressed. An intelligence consisting of a USB or LSB signal is then fed through relay A3K5 to IF amplifier A3Q4.

The DATA and CW modes are similar in function to the SSB modes since USB is always used for DATA and CW operation.

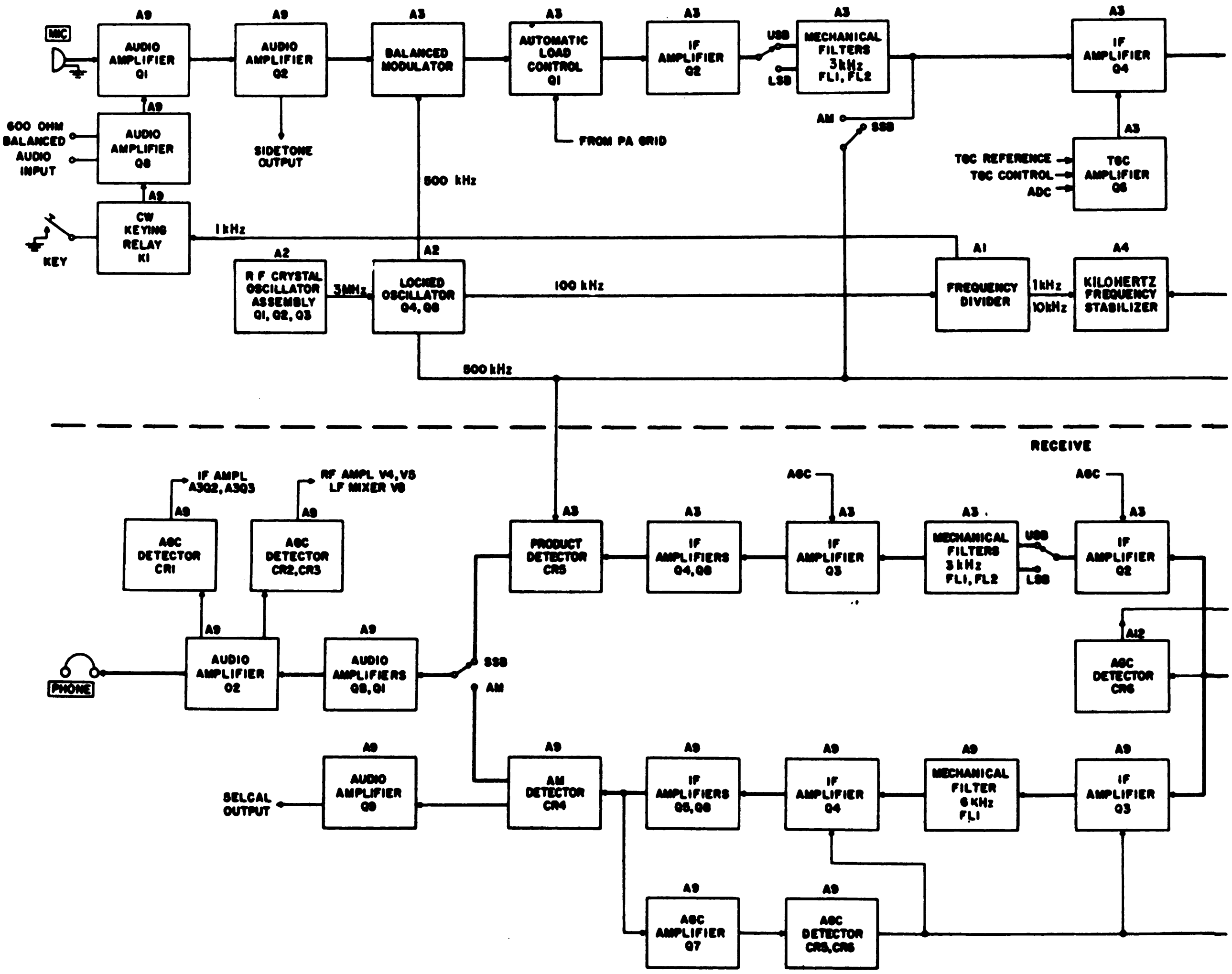

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Figure 1-5.—AN/ARC-94, simplified block diagram.

The desired signal is amplified in A3Q4 and fed to transmit LF mixer A12V1. Transmitter gain control amplifier A3Q6 controls the output transmission level by adjusting the gain of A3Q4 in accordance with control voltages provided in the form of a transmitter gain control signal and an automatic drive control signal.

RF TRANSLATOR SECTION.—The desired signal is mixed in A12V1 with a preselected output from the variable frequency oscillator (VFO) in the carrier generator function. The output circuit of A12V1 is tuned to the difference frequency of the two signal inputs to the mixer. The frequency range of the output signal from the transmit LF mixer is 2.001 MHz to 3.00 MHz in 1-kHz increments. If the selected output frequency is to be in the range of 2.0 MHz to 6.999 MHz, the LF mixer output signal is coupled to transmit 17.5-MHz mixer A12V2. A signal is also applied to A12V2 from 17.5-MHz oscillator A12V10. The output circuit of A12V2 is tuned to the difference frequency of the two signals to produce an output frequency in the

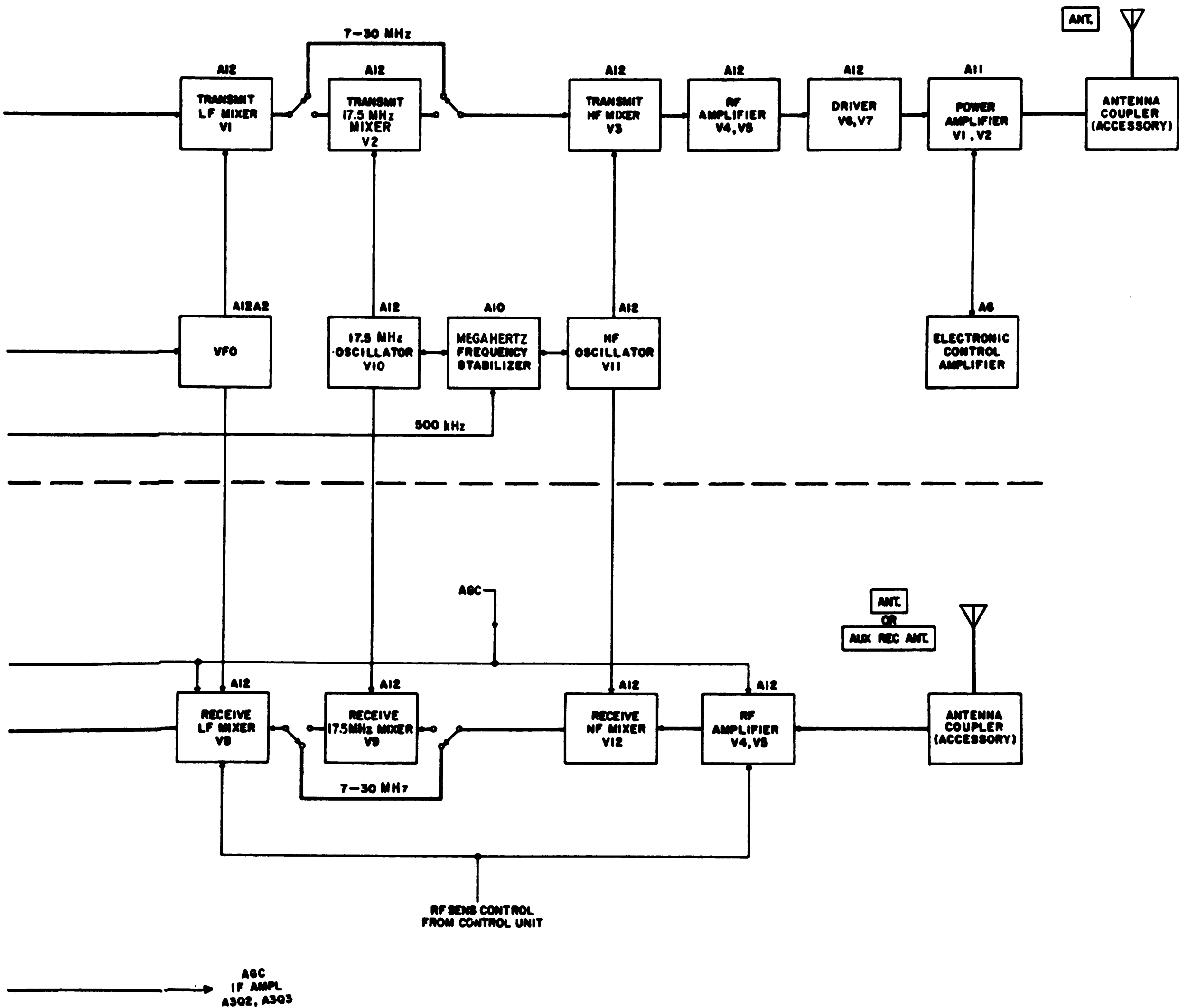

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Figure 1-5.—AN/ARC-94, simplified block diagram—Continued.

range of 14.5 MHz to 15.5 MHz. If the selected output frequency is to be in the 7.0-MHz to 30.0-MHz range, the output of A12V1 is coupled directly to A12V3. A signal is also applied to A12V3 from HF oscillator A12V11. The difference frequency of the two input signals mixed in A12V3 is at the desired output frequency and is amplified by RF amplifiers A12V4 and A12V5 and fed to drivers A12V6 and A12V7. The driver output is fed to power amplifiers A11V1 and A11V2.

POWER AMPLIFIER SECTION.—The power amplifier is bandswitched by the autopositioner and tuned by a servo-driven inductance in electronic control amplifier module A6. The output of the power amplifier is designed for a 52-ohm unbalanced load and is applied to the transmitting antenna through an antenna coupler.

Receive Function

The receive function includes an RF input section, a first and second conversion section, an SSB channel, an AM channel, and an audio section.

The RF input section receives the desired signal broadcast by the remote station. The signal is amplified and sent to the first and second conversion sections, where a double conversion is performed to bring the signal to the desired intermediate frequency. In SSB, DATA, and CW modes, the AM channel is disabled and the desired signal is brought to the SSB channel. After being amplified to a suitable level, the desired SSB signal is demodulated in a product detector. The resultant audio signal is amplified in the audio section and applied to headset phones.

In AM mode, the SSB channel is disabled and the desired signal is brought to the AM channel. In the AM channel, a standard AM detector is used to demodulate the signal. All other functions are similar to those which occur in the SSB channel.

COMMON STAGES.—The receive function of the AN/ARC-94 uses many stages in common with the transmit function. Function selection is controlled by the operator with a push-to-talk switch. When the switch is operated, the transmit function is actuated. At all other times the receive function is actuated. A relay operated switching system shifts the assignments of the common stages between transmit and receive functions as required.

RF INPUT SECTION.—The RF input section receives the desired signal from a remote station. The impedance of the antenna is matched to that of amplifiers A12V4 and A12V5 by a suitable coupler device to ensure maximum energy transfer. The amplifiers step up the received signal and apply it to receive HF mixer A12V12 in the first conversion group. RF gain is manually adjustable from the C-3940/ARC-94. The RF amplifiers are also under AGC system control.

CONVERTER SECTION.—The output of A12V4 and A12V5 is fed to receive HF mixer A12V12 where it is mixed with the signal from HF oscillator A12V11 in the carrier generator section. The output of A12V12 is coupled to receive 17.5-MHz mixer A12V9 if the operating frequency is in the range of 2.0 MHz to 6.999 MHz. It is coupled to receive LF mixer A12V8 if the operating frequency is in the range of 7.0 MHz to 30.0 MHz. The output from A12V8 is a 500-kHz IF signal. The 500-kHz IF signal is fed to either the SSB or AM channel.

SSB AND AM CHANNELS.—In SSB mode, the 500-kHz IF signal is applied to one of two mechanical filters, A3FL1 or A3FL2. Each mechanical filter has a bandwidth of 2.7 kHz. One filter passes the upper sideband, and the other passes the lower sideband. The appropriate filter is selected at the mode selector on the C-3940/ARC-94. The filter output is amplified in IF amplifiers A3Q3, A3Q4, and A3Q5. The output of A3Q5 is applied to product detector A3CR5 which recovers the audio signal.

In AM mode, the output of A12V8 is fed to IF amplifier A9Q3 for amplification and is coupled to 6-kHz mechanical filter A9FL1. The signal is then fed to three more IF amplifiers, A9Q4, A9Q5, and A9Q6. The output of A9Q6 is fed to diode detector A9CR4 which recovers the audio signal and applies it to the audio section.

AUDIO SECTION.—In either channel, the desired audio signal is amplified in audio amplifiers A9Q1, A9Q8, and A9Q2, and fed to the operator's headset. Selcal (selective calling) signals detected in AM detector A1CR4 are fed to audio amplifier A9Q9 and are coupled to the rear connector of the RT-648/ARC-94. Selcal signals are detected in all modes of operation.

Carrier Generator Function

The carrier generator function includes RF oscillator A2, frequency divider A1, kilohertz-frequency stabilizer A4, variable frequency oscillator (VFO) A12A2, 17.5-MHz oscillator A12V10, megahertz-frequency stabilizer A10, and HF oscillator A12V11.

FREQUENCY GENERATION AND STABILIZATION.—The AN/ARC-94 transmits and receives on every 1-kHz increment from 2.000 MHz to 29.999 MHz. This provides 28,000 possible separate operating frequencies. The operating frequency is selected at the C-3940/ARC-94.

The 100-kHz, 10-kHz, and 1-kHz frequency selector knobs on the C-3940/ARC-94 actuate autopositioner A12A1. The autopositioner mechanically tunes variable frequency oscillator A12A2 over the range from 2.501 MHz to 3.500 MHz in 1-kHz increments. The megahertz frequency selector knob on the C-3940/ARC-94 controls a motor in RF translator module A12. This motor switches tuning elements which tune HF oscillator A12V11 to one of 28 different frequencies. The HF oscillator, in conjunction with 17.5-MHz oscillator A12V10, provides 28 1-MHz bands for each of the 1-kHz increments from variable frequency oscillator A12A2.

Megahertz-frequency stabilizer module A10 stabilizes the frequency of A12V10 and A12V11 by comparing each oscillator frequency with the frequency of a spectrum point derived from the 500-kHz output of RF oscillator module A2. The coarse frequency of A12V11 is controlled by the motor in RF translator module A12. The frequency range of A12V11 is 8.5 MHz to 32.0 MHz. The output of A12V11 is tuned to the second harmonic of the fundamental oscillator frequency when the selected operating frequency of the RT-648/ARC-94 is in the range of 14.0 MHz to 29.999 MHz. This signal is coupled to transmit HF mixer at A12V3, and to receive HF mixer A12V12.

The extremely high stability of the AN/ARC-94 operating frequency is obtained by basing frequency control of the entire RT-648/ARC-94 on the frequency of a very stable crystal oscillator located in RF oscillator module A2. Frequency stability of this crystal oscillator is assured by utilizing a temperature-compensating network.

The HF and 17.5-MHz oscillators are frequency locked, and the variable frequency oscillator is phase locked to the crystal generated reference frequency by circuits in the megahertz- and kilohertz-frequency stabilizer modules. The IF injection frequency is derived from the crystal oscillator. The RT-648/ARC-94 operating frequency is thus held accurate within ±0.8 part per million per month from −40 °C (−40 °F) to +75 °C (+167 °F).

Keying Circuits

When the RT-648/ARC-94 is keyed, the keying circuits actuate the stages that must operate if the RT-648/ARC-94 is to transmit, while disabling receiver circuits that would interfere with transmission. When the key is released, the keying circuits operate to switch off the transmitter and switch common stages from the transmit to the receive function.

Sidetone Circuits

The sidetone signal is taken from audio amplifier stage A9Q2 to provide audio monitoring in the transmit mode. The audio signal from the audio amplifier is fed through a keying relay and a sidetone relay (not shown) to the audio output. A combination of two voltages is used to energize the sidetone relay.

One voltage is derived from the RF output of power amplifier module A11. This RF output is rectified, filtered, and applied to the sidetone relay coil.

The second voltage, from 3-phase high-voltage power supply module A7 (not shown), is proportional to the power amplifier plate current. This voltage is the same one used for transmitter gain control in IF translator module A3. To energize the sidetone relay, sufficient plate current and plate voltage swing must be present in the power amplifier. A capacitor is placed across the coil of the sidetone relay to keep the relay energized in the sideband transmit mode when the plate current varies with the applied audio signal.

Recycle Circuits

The recycle circuits are activated when any of the frequency selector knobs on the C-3940/ARC-94 are turned. When any autopositioner operates, the recycle relay (not shown) is energized, and remains energized so long as any tuning motor is operating. The recycle relay has the following functions:

1. Disconnects transistor supply voltage to the audio amplifier in order to mute the audio during the tuning cycle.
2. Provides a ground to activate the antenna tuner.
3. Interrupts the operation of kilohertz-frequency stabilizer module A4 during the tuning cycle.
4. Disconnects the keying circuit so that the transmitter cannot be keyed during the tuning cycle.

VHF TRANSCEIVERS

The main purpose of VHF transceivers is to provide two-way communications between aircraft, ships, and shore stations. They normally operate within the frequency range of 116 MHz to 149.95 MHz. Some VHF transceivers are dual purpose, their receivers being utilized in conjunction with very high-frequency omnidirectional rapid range (VOR) navigation systems. When used for this purpose, the frequency range of the receiver is extended to cover 108 MHz to 151.95 MHz. (NOTE: VOR systems will be covered in detail in Chapter 2.) Since VHF transceiver circuits function much the same as UHF transceivers, we will omit the theory of operation at this time and cover it under UHF transceivers. The only basic difference between VHF transceivers and the AN/ARC-159 (to be covered under UHF transceivers) is the frequency range of the transceiver.

UHF TRANSCEIVERS

There are two main types of UHF transceivers: frequency modulated (FM) and amplitude modulated (AM). We will discuss the AN/ARC-88 FM and AN/ARC-159 AM, since they are typical in theory of those in use in the Navy today.

AN/ARC-88 FM TRANSCEIVER

The purpose of Radio Set AN/ARC-88 is to provide a UHF frequency-modulated radio link between aircraft, shore, and ship. Radio Receiver-Transmitter RT-649/ARC-88 is partially transistorized equipment capable of transmitting and receiving on any one of 1,750 frequency channels, spaced at 100-kHz intervals in the 225.0-MHz to 399.9-MHz range. The equipment receives and transmits multiplexed data information originating in the form of digital pulses from an associated equipment of a digital data communication system.

Radio Set AN/ARC-88 is supplied digital information from associated data equipment and transmits it on a frequency-modulated carrier signal. It also receives a similar frequency-modulated signal, demodulates the signal, and supplies the resulting pulses to the associated data equipment. Reception and transmission are on the same frequency and utilize the same antenna.

Radio Set Control C-2736A/AR provides remote selection of the 1,750 frequency channels or 19 preset channels within the specified range. (The frequencies of the 19 preset channels are determined by adjustment of a memory drum on the front panel.)

Major Components

Radio Set AN/ARC-88 consists of Radio Receiver-Transmitter RT-649/ARC-88, Mounting MT-2653/ARC, Standing Wave Ratio Indicator IM-178/ARC-88, Electronic Equipment Air Cooler HD-513/ARC, and Radio Set Control C-2736A/AR. The following paragraphs provide a brief description of these components, followed by a brief discussion of the general principles of operation of the equipment.

RECEIVER-TRANSMITTER.—Radio Receiver-Transmitter RT-649/ARC-88 consists of a main chassis, dust cover, and nine plug-in modules. The nine plug-in modules are mounted on the main chassis and enclosed in an aluminum case. An airtight seal is provided between the cover and the main chassis to permit the modules of the component to be pressurized. External cooling air is forced by the external blower through the base casting to the heat exchanger and expelled at the bottom of the unit. (See fig. 1-6.) Internal air is circulated through the internal cores of the heat exchangers, through the plenum chamber formed by the main chassis, and through each module by an internal blower. In this manner, the heat from the component is dissipated.

An antenna, two power connectors, and a pressurizing valve are mounted on the front panel. A toolkit containing special tools for maintenance is supplied with Radio Receiver-Transmitter RT-649/ARC-88.

MOUNTING.—Mounting MT-2653/ARC provides a mounting base for Radio Receiver-Transmitter RT-649/ARC-88. Vibration isolators which are usually a part of the mounting are an integral part of the mounting base casting of the RT-649/ARC-88.

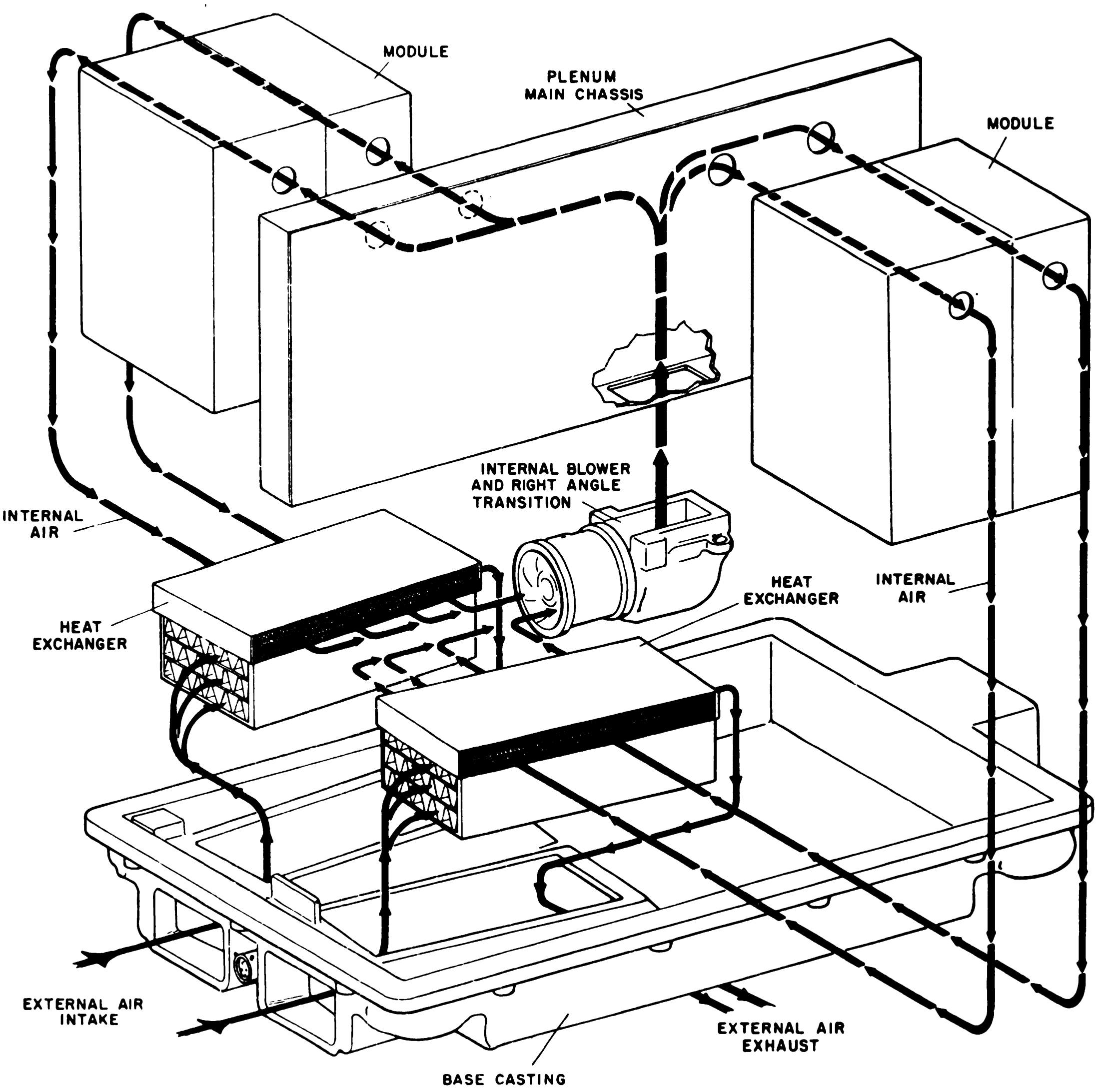

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Figure 1-6.—Cooling airflow diagram.

SWR INDICATOR.—Standing Wave Ratio Indicator IM-178/ARC-88 provides the operator with a remote indication of transmitter power output. It is secured to the front panel of the RT unit by three cross-recessed screws. When the set is in transmit operation, the remote meter indicates incident power. By changing the connection of the remote cycle indicator to the other wire on the multiwire cable, a reflected power measurement may be obtained.

AIR COOLER.—Electronic Equipment Air Cooler HD-513/ARC is made up of a casting, single-phase blower motor, and an air inlet filter assembly. It is secured to the rear of the RT unit by four hex-socket screws. The HD-513/ARC operates when the internal temperature of the RT unit exceeds 35 °C (95 °F).

CONTROL UNIT.—Radio Set Control C-2736/AR is used to control Radio Receiver-Transmitter RT-649/ARC-88. A selector switch

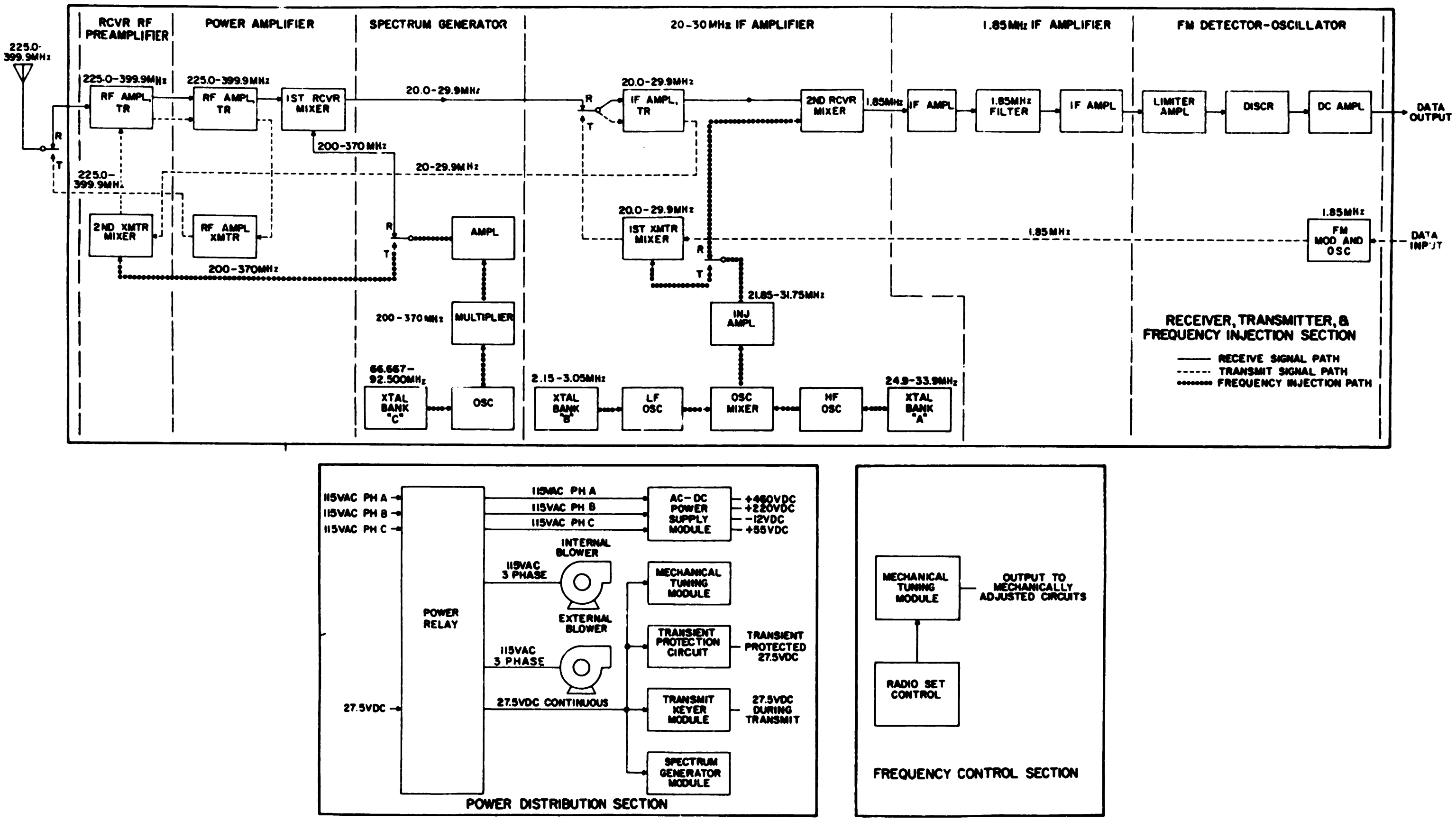

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Figure 1-7.—AN/ARC-88, simplified block diagram.

on the front panel makes 19 preset channels available to the operator. This selector switch has complete control of selection unless it is set to the M (MANUAL) position. In the M position, adjustment of the four MANUAL frequency controls operates switches which activate an autopositioner, located in the RT unit, to set up operation at the selected frequency. A three-position rotary power switch on the front panel controls the power on-off and the selection of the associated radio equipment. Frequency adjustments for preselected channels are made by lowering a small panel at the bottom of the front panel.

Principles of Operation

Radio Receiver-Transmitter RT-649/ARC-88 is a remotely controlled receiver and transmitter which makes use of the double-conversion superheterodyne principle. Two sources of injection frequencies are heterodyned with the signal input during receiving operation, or heterodyned with a developed carrier during transmitting operation, to produce the desired intermediate frequencies. (See fig. 1-7.)

The higher injection frequencies are developed in the spectrum generator module and are in the 200-MHz to 370-MHz range. The fundamental signals are produced by a crystal oscillator, fed through a frequency multiplier, amplified, and then applied to the first receiver mixer or the second transmitter mixer stage.

The lower injection frequencies in the 21.85-MHz to 31.75-MHz range are produced in the oscillator stages of the 20- to 30-MHz IF amplifier module by mixing the output of two crystal oscillators. One of these oscillators provides an output in the range of 24.9 MHz to 33.9 MHz and the other 2.15 MHz to 3.05 MHz. The heterodyne difference frequency in the 21.85-MHz to 31.75-MHz range is amplified and applied to the second receiver mixer or to the first transmitter mixer stages. Relays accomplish circuit switchover from receiver to transmit operation.

The crystal-controlled frequency generation and injection systems are ganged mechanically to the tuning mechanism of the RT unit. All tuning or channeling is accomplished by the mechanical tuning module, in response to Radio Set Control C-2736A/AR.

The received signal, consisting of a frequency-shift-keyed (FSK) carrier within the range of 225.0 MHz to 399.9 MHz, is fed from the antenna through an antenna relay into the amplifier circuits of the receiver RF preamplifier module, and applied to an RF amplifier circuit of the power amplifier module. In the power amplifier module, the received signal is further amplified and mixed with the 200-MHz to 370-MHz injection voltage output of the spectrum generator module. The resultant 20.0-MHz to 29.9-MHz first intermediate frequency is applied to the 20- to 30-MHz IF amplifier module where it is mixed with the 21.85-MHz to 31.75-MHz output from the two crystal oscillators within the 20- to 30-MHz IF amplifier module. The heterodyned difference between the first intermediate frequency and the output from the 20- to 30-MHz IF amplifier module crystal oscillators is mixed in the 20- to 30-MHz IF amplifier module to produce the 1.85-MHz second intermediate frequency. This output is fed through a 1.85-MHz filter, four stages of IF amplification, and two limiter stages to a discriminator. After demodulation, the data signal is amplified in two dc amplifier stages and fed to the associated data equipment.

The operation of transfer relays and electron tube switching, from receive to transmit or from transmit to receive operation, is accomplished by the transmit keyer module in response to data input signals from the associated data equipment.

During transmission, the initial excitation is obtained from a frequency modulator and oscillator in the FM detector-oscillator module which operates at a center frequency of 1.85 MHz and is frequency modulated with the data information furnished from the associated data equipment. The 1.85-MHz frequency-modulated signal is mixed with the 21.85-MHz to 31.75-MHz injection signal from the two crystal oscillators within the 20- to 30-MHz IF amplifier module. The heterodyned difference between the 1.85-MHz signal and the oscillator injection signal produces the 20-MHz to 29.9-MHz intermediate frequency. The 20-MHz to 29.9-MHz intermediate frequency is fed through two stages of amplification in the 20- to 30-MHz IF amplifier module and mixed in the second transmitter mixer stage of the receiver RF preamplifier module with the 200-MHz to 370-MHz injection output from the spectrum generator module. The resultant carrier frequency of 225.0 MHz to 399.9 MHz is then fed through two stages of amplification in the receiver RF amplifier module, three stages of amplification in the power amplifier module, and applied to the antenna.

Channel Selection

The set contains provisions for either automatic or manual selection of the operating frequency channel. Selections of channeling mode and operating frequency are made at the control unit. Actual tuning is accomplished by mechanical linkages in the mechanical tuning module.

Both automatic and manual channel selection are accomplished by tuning the tank circuits of the receiver RF preamplifier, power amplifier, 20- to 30-MHz IF amplifier, and spectrum generator modules for reception or transmission on the selected frequency.

In regard to channel selection, the terms automatic and manual are used to differentiate between the selection of one of 19 preset channels by rotating the channel selector switch, and the selection of one of 1,750 frequency channels by individual setting of the manual frequency controls. In either case, the actual mechanical and electrical tuning operations within the equipment are fully automatic.

Selection of any frequency is initiated when the operator rotates the decade selector to the desired frequency. By rotating a particular decade selector, the switch circuit that corresponds to the new frequency setting is grounded. By grounding the switch circuit, the positioning system of the mechanical tuning module is energized and produces a synchronized rotation of the gear train in the prescribed direction by a predetermined amount. The motion imparted to the gear train automatically adjusts the module-tuned circuits for operation of the equipment on a selected frequency.

A simplified positioning system to illustrate the principle is shown in figure 1-8. The selector switch (remote control switch) chooses the operating frequency, and the seeking switch determines the angular position to which the drive motor rotates the shaft for a specific selected frequency. As shown, the equipment is at rest with the selector switch and the seeking switch at position 1. When the switches are at the corresponding position, no contact of the seeking switch is grounded through the selector switch; the electrical circuit of the drive motor is broken by the open motor control contacts of the deenergized relay.

The drive motor, which has driven the seeking switch to reset at position 1, has also driven the module tank circuits to the selected frequency in the same angular rotation.

Assume the selector switch is rotated so that the tab of the selector contacts the terminal at position 2. A closed path to ground then is completed from the +27.5-volt supply through the relay coil, the common contact and contact 2 of the seeking switch, through contact 2 of the selector switch, and to ground through the common contact of the selector switch. Relay K1 is energized and closes the motor control contacts; the drive motor then rotates in the predetermined direction. The seeking switch, which is geared to the drive motor, is driven until the cutout of the seeking switch is adjacent to position 2. At this position, the 27.5-volt path is opened, the relay releases, the motor stops, and the system comes to rest. Since the seeking switch and the tuned circuits are gear-driven by the motor, the tuned circuits are driven through the required angular displacement, which is proportional to the seeking switch travel from position 1 to position 2.

As illustrated in figure 1-8, the switch arrangement includes a notched stop wheel and pawl that accurately positions the seeking switch as soon as the drive motor is deenergized, and a clutch that decouples the switches from the drive motor and gear train when the final position is reached. Although not shown in figure 1-8, the clutch permits a single motor to drive several seeking switch shafts.

Assume the selector switch is rotated so that the circuit having the increments of the selected frequency is grounded. A complete path to ground is provided from the 27.5-volt supply through the relay coil, the seeking switch, the applicable control wire, and the selector switch. The actuated relay withdraws the pawl from the notch along the periphery of the stop wheel and

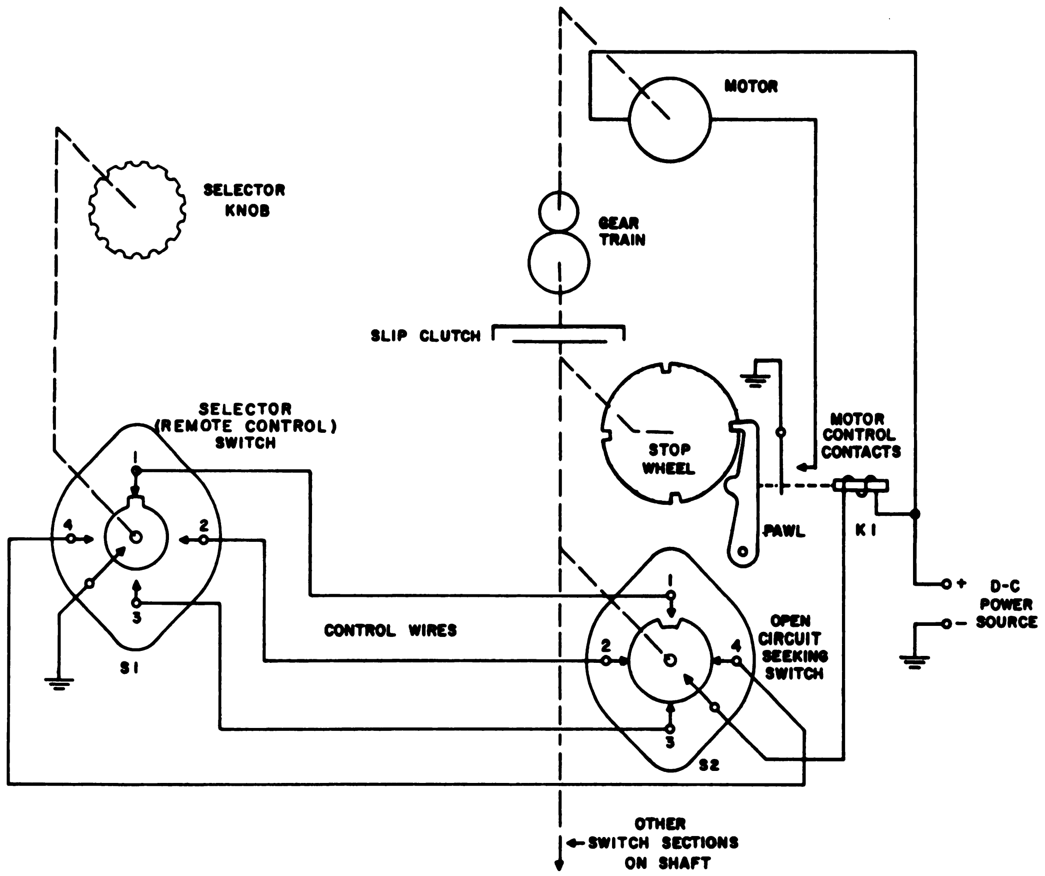

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Figure 1-8.—Automatic positioning, functional diagram.

energizes the drive motor through the closed motor control contacts of the relay.

The subsequent rotation of the drive motor, which is in a predetermined direction, drives the gear train, clutch, stop wheel, and seeking switch. The motor rotation is continuous until the motor (and tuning gear train) has rotated through the required tuning angle; at this point, the corresponding contact of the seeking switch is open, breaking the path to ground from the 27.5-volt supply. The relay releases, permitting the pawl to engage a stop wheel notch at which time the motor control contacts open. The subsequent loss of stop wheel motion brakes the seeking switch and shaft. The kinetic energy of the drive motor (which persists after the removal of the drive motor source power) is dissipated in the gear train and clutch. At rest, the seeking switch and shaft are in a position synchronous with the position of the selector switch.

In actual practice, to ensure proper positioning of the stop wheel, the seeking switch opens the relay circuit shortly before the stop wheel reaches the notch to be engaged by the pawl. The relay motor control contacts are operated mechanically by the pawl arm so the contacts remain closed until the pawl drops into the prescribed notch.

The channel selector circuits of Radio Receiver-Transmitter RT-649/ARC-88 and Radio Set Control C-2736A/AR are more complex, but use the principles of the single selector-seeking system shown in figure 1-8. The actual system, however, employs three selector-seeking switch groups which are driven by a single

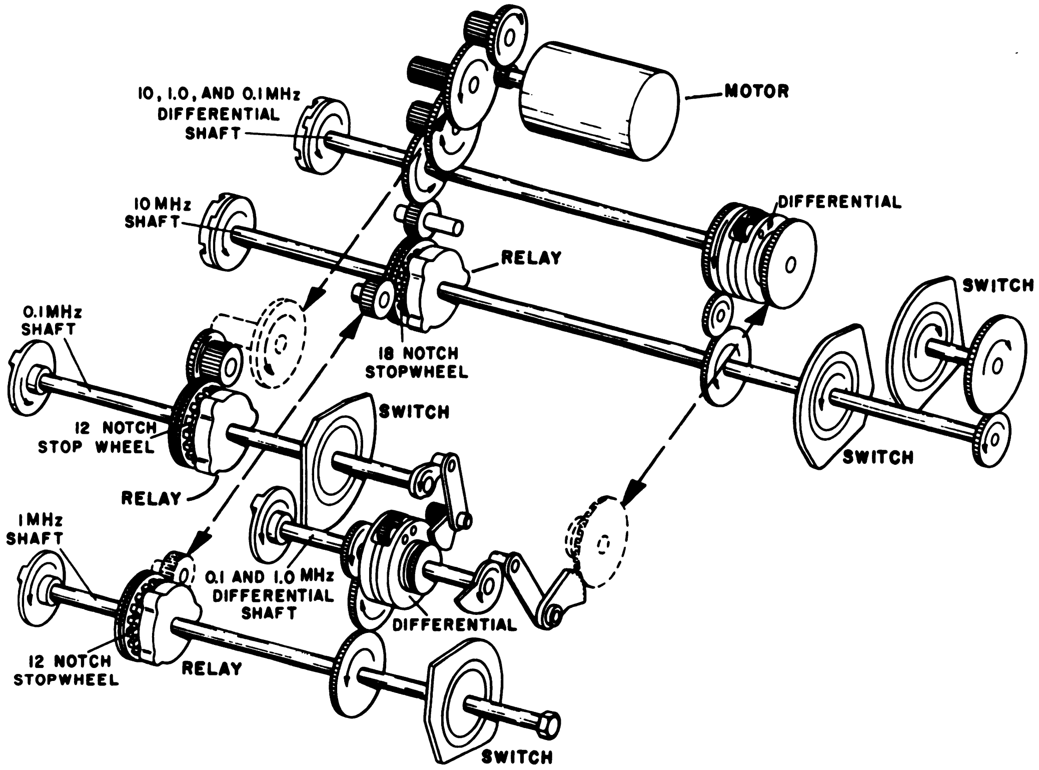

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Figure 1-9.—Mechanical turning linkages.

motor. (Refer to figure 1-9.) Each of the three groups has individual switch connections, relay, pawl, stop wheel, and relay motor contacts.

The seeking switches are driven by the motor through three separate friction-type slip clutches, one of which is attached to each of the three primary shafts. When a pawl is not engaged in a stop wheel notch, the tension in the clutch spring is sufficient to allow the motor to turn the seeking switch shaft. When the stop wheel is held by the pawl, the motor side of the clutch can rotate while the seeking switch side of the clutch remains motionless. Several seeking switch shafts thus may be independently positioned by a single drive motor and gear system.

The channel selector system is, essentially, a three-section decade system that allows two alternative methods of inserting a different frequency setting: automatic, wherein any one of 19 preset channels may be selected by the channel selector switch, and manual, wherein

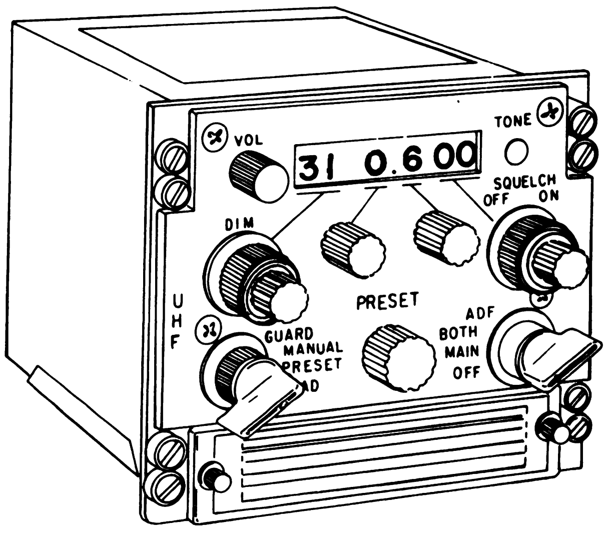

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Figure 1-10.—Radio Transceiver AN/ARC-159.

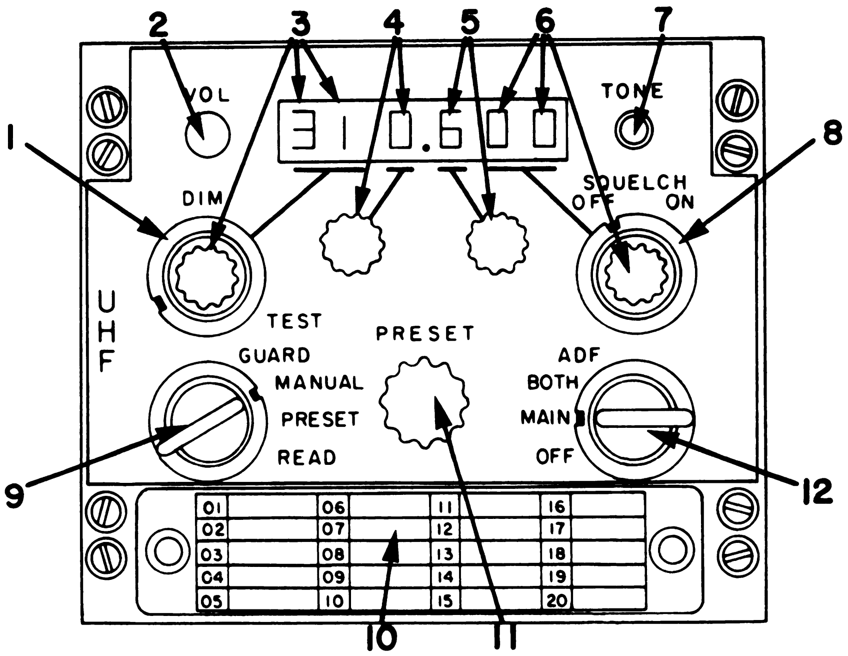

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Figure 1-11.—Radio Transceiver AN/ARC-159, Front View, operating controls and indicators.

any one of 1,750 channels may be selected by means of four separate decade selectors, each of which must be set up individually for the frequency increment within its range. The two methods may both be subdivided into four parts consisting of the 200-MHz to 300-MHz, 10-MHz, 1.0-MHz, and 0.1-MHz decade selectors.

AN/ARC-159 UHF AM TRANSCEIVER

The transceiver provides two-way amplitude modulated communications between aircraft, shore stations and ships. It transmits and receives in the frequency range of 225 MHz to 399.975 MHz. In addition, it can provide wideband (data or secure voice) communications and automatic direction finding reception (ADF) when used in conjunction with other equipment and antennas. (NOTE: ADF operation will be discussed in detail in Chapter 2.)

The set employs a separate guard receiver, which is fixed tuned to 243 MHz, the International Distress Frequency. This guard receiver can be monitored simultaneously with the main receiver if desired.

The transceiver (see fig. 1-10) is a compact, panel (console) mounted unit, measuring only 9-1/4 x 5-3/4 x 4-5/8 inches, and weighing just 8-3/4 pounds. All operating controls are located on the front of the unit. The transceiver can be manually tuned to any of 7,000 frequencies in 25-kHz increments from 225 MHz to 399.975 MHz. (See fig. 1-11 and table 1-2 for operating controls and their functions.) The unit also employs 20 preset frequency channels which may be preset by properly coding the memory drum found behind the front panel access door. (See fig. 1-12.)

Functional Theory of Operation

The transceiver (see fig. 1-13) consists of six sections:

1A1 Frequency synthesizer
1A2 RF translator/modulator
1A3 IF/audio amplifier
1A4 Guard receiver
1A5 Power amplifier/power supply
1A6 Control

Table 1-2.—Radio Transceiver AN/ARC-159, controls and indicators

ITEM NO (figure 1-11)	CONTROL	DESCRIPTION	FUNCTION
1	DIM-TEST	Wafer switch	Adjusts light intensity of readout. Tests readout when switch is set to TEST.
2	VOL	Potentiometer	Adjusts audio output level.
3	Frequency	Wafer switch and readout	Selects and indicates 100-MHz and 10-MHz frequency increments during manual operation.
4	Frequency	Wafer switch and readout	Selects and indicates 1-MHz frequency increments during manual operation.
5	Frequency	Wafer switch and readout	Selects and indicates 0.1-MHz frequency increments during manual operation.
6	Frequency	Wafer switch and readout	Selects and indicates 00-, 25-, 50-, and 75-kHz frequency increments during manual operation.
7	TONE	Momentary contact push-button switch	Modulates transmitted signal with 1020-Hz tone.
8	SQUELCH	Wafer switch	Enables or disables main receiver squelch.
9	Mode selector	Wafer switch	
	GUARD		Tunes receiver-transmitter to guard frequency. Displays guard frequency on readout.
	MANUAL		Permits manual selection of frequency. Selected frequency is displayed on readout.
	PRESET		Permits selection of any of 20 preset channels. Displays selected channel number on readout in fourth- and/or fifth-digit position.
	READ		Displays frequency of selected preset channel on readout.
10	Chart	Operating frequency chart	Provides semipermanent record of preset frequencies.
11	PRESET	Memory drum switch assembly	Preset channel selector. Sets channel when mode selector is PRESET.
12	Function selector	Wafer switch	
	OFF		Turns off power to receiver-transmitter.
	MAIN		Selects normal receiver and transmit operation. Transmitter is keyed by microphone push-to-talk switch.
	BOTH		Enables guard receiver in addition to functions described for MAIN.
	ADF		Enables automatic direction-finding equipment. Main and guard receivers are enabled.

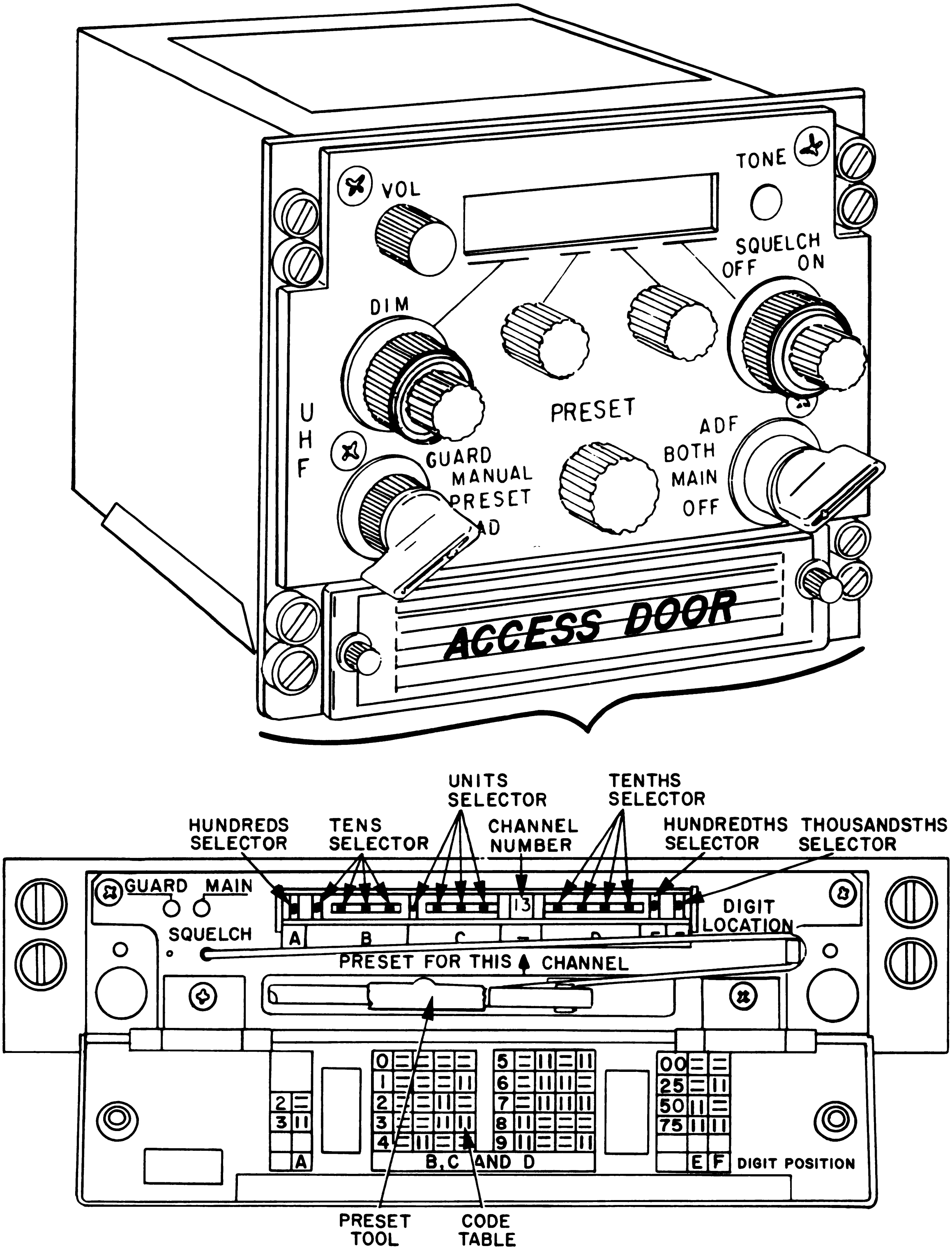

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Figure 1-12.—ARC-159 with access door open.

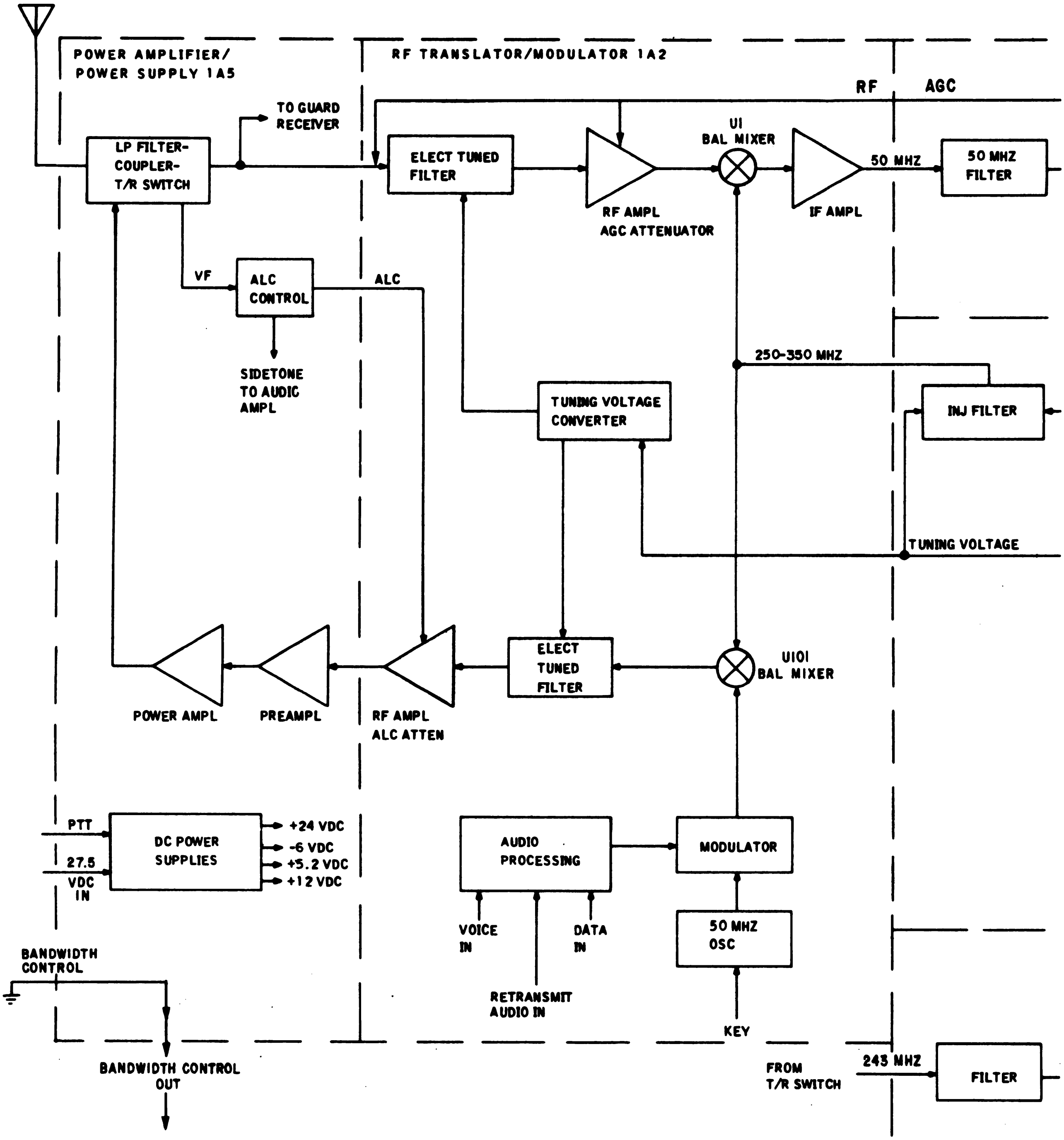

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Figure 1-13.—AN/ARC-159 Simplified block diagram.

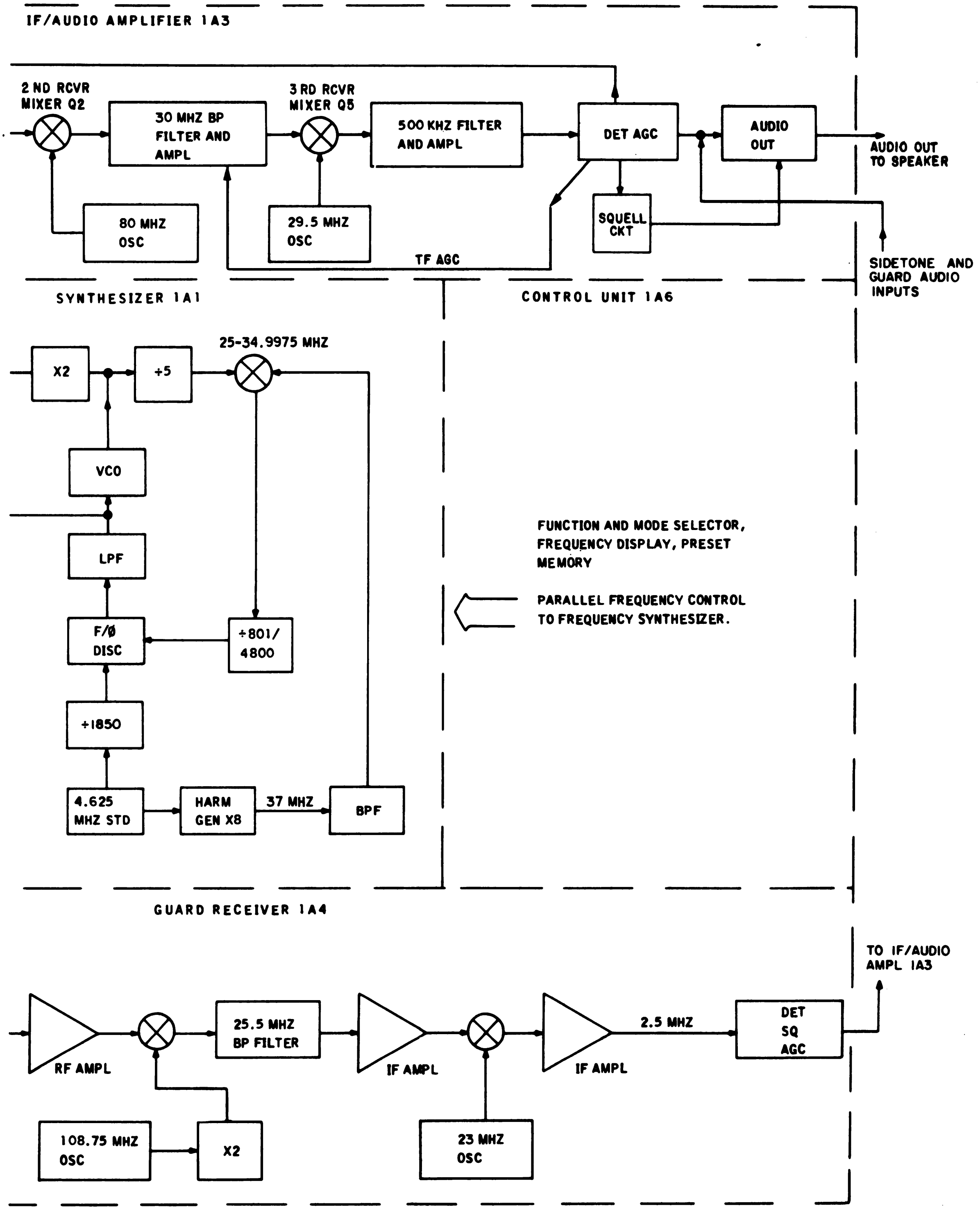

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Figure 1-13.—AN/ARC-159 Simplified block diagram—Continued.

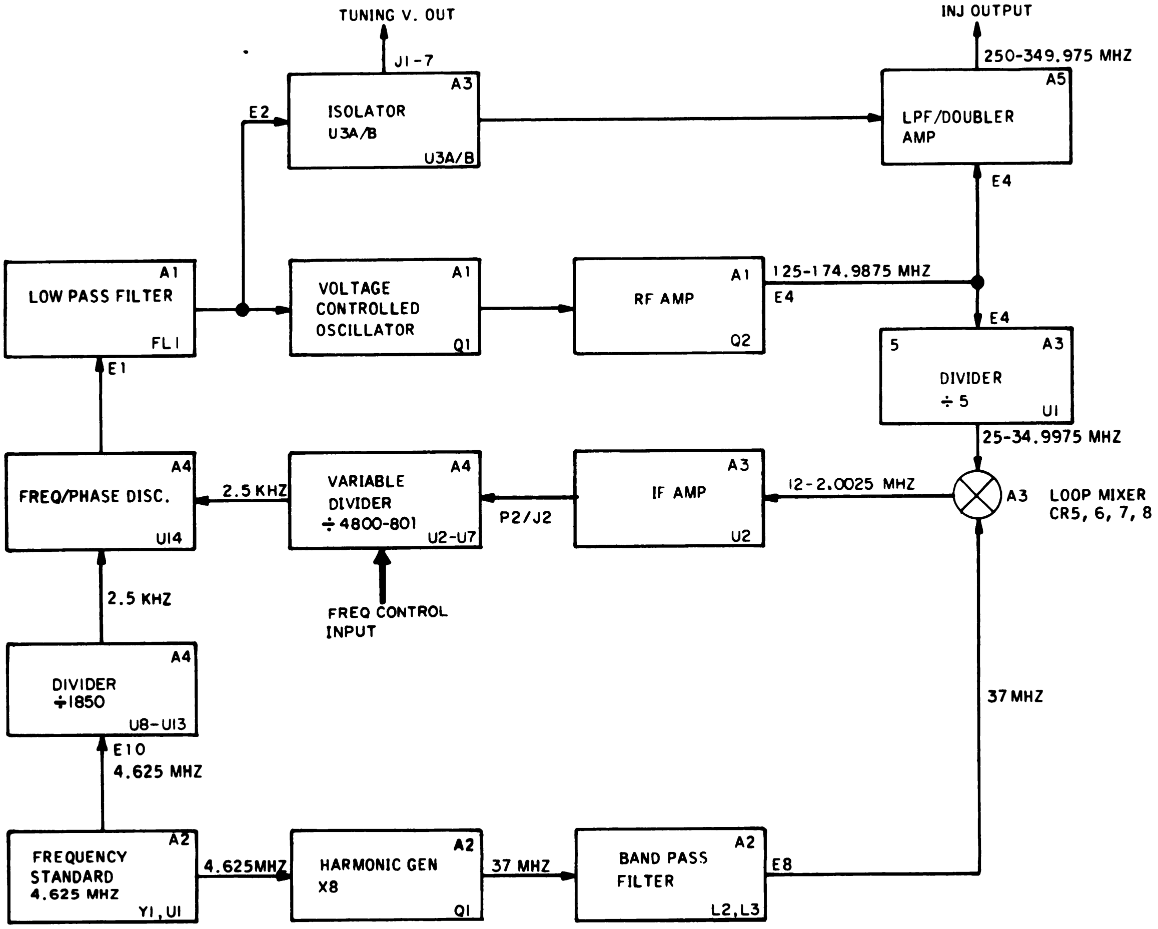

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Figure 1-14.—Radio Set AN/ARC-159, Frequency Synthesizer 1A1, block diagram.

Before we discuss the overall operation in either receive or transmit mode, let's first analyze the functions of the individual sections. Refer to figure 1-13, as well as the individual section figures during the following discussions.

FREQUENCY SYNTHESIZER 1A1.—The frequency synthesizer 1A1 section (see fig. 1-14) provides the mixer injection frequencies and tuning voltage needed by the RF translator/modulator 1A2 section. The synthesizer output frequency is determined by binary-coded decimal (BCD) information from the control unit 1A6 section. The synthesizer uses a phase-locked loop with a single frequency conversion. The voltage controlled oscillator (VCO) 1A1A1Q1 operates in the frequency range of 125 MHz to 174.9875 MHz. The actual operating frequency is determined by a control voltage (discriminator error) signal. The VCO output (125-174.9875 MHz) is buffered by RF amplifier 1A1A1Q2 and applied to the inputs of frequency doubler/amplifier 1A1A5 and frequency divider (divide by 5) 1A1A3U1. The frequency doubler amplifier output (250-349.975 MHz) is routed to RF translator/modulator 1A2 balance mixers. The frequency divider output (25-34.9975 MHz) is applied as one input to loop mixer 1A1A3. The second input to the loop mixer comes from the output of the crystal-controlled frequency standard oscillator 1A1A2Y1,U1. The output of this oscillator (4.625 MHz) is routed to a harmonic generator, the output of which is a 37-MHz signal (the eighth harmonic of 4.625 MHz.) The output of the loop mixer (2.0025 to 12.0 MHz) is the difference frequency of the two inputs. This signal is amplified by IF amplifier 1A1A3 and routed to variable divider 1A1A4. The division ratio is determined by the frequency setting of the control section 1A6 and varies from 4800:1 to 801:1. The output of the variable divider should be 2.5 kHz. Since the output of the variable divider is predetermined by the control frequency settings, any error in the frequency out of the VCO will result in a signal that differs from 2.5 kHz out of the divider. The divider output is applied to frequency/phase discriminator 1A1A4U14 where it is compared with 2.5 kHz signal which was derived by the frequency standard (4.626 ÷ 1850). Any difference between these two signals will be detected and will appear at the discriminator output as a dc error voltage. The error voltage is applied through a low-pass filter (LPF) to the VCO to correct its operating frequency, and to RF translator/modulator 1A2 via isolator 1A1A3U3A/B to its tuning voltage converter to tune electronic filters to the correct operating frequency.

RF TRANSLATOR/MODULATOR 1A2.—The RF translator/modulator 1A2 section, contains both receive and transmit circuits. (See fig. 1-15.) In the receive mode, the module filters, amplifies, and translates (converts) the RF input signal to 50 MHz. In the transmit mode, it amplifies, translates, filters, and modulates the injection signal (such as voice from a microphone) to provide excitation (modulation) to power amplifier/power supply 1A5.

In the transmit mode, normal voice (audio) is applied to modulator Q202 via isolation buffer, clipper circuits. The purpose of these circuits is to maintain the input audio to the modulator at a constant level to prevent overmodulation. Also applied to Q202 are 1020-Hz tone, retransmit audio and data information (such as encrypted audio) if these circuits are enabled. The 50-MHz oscillator is enabled by the microphone key line. This output is also applied to the input to Q202. The resulting output of the modulator Q202 is a 50-MHz signal which is amplitude modulated by either the voice, retransmit audio or data signal. From here on, we will utilize the voice signal, but keep in mind the circuits are similar for the other modes of operation. The modulator output is applied to the transmit balanced mixer U101. In the mixer, the 50-MHz signal is mixed with the 250-349.975 MHz output of the frequency synthesizer 1A1. For transmit frequencies of 299.975 MHz and below, the frequency synthesizer signal is 50 MHz above the desired transmit frequency, and the output of the mixer is the difference frequency. For transmit frequencies above 300 MHz, the frequency synthesizer signal is 50 MHz below the desired transmit frequency and the output of the mixer is the sum frequency. The mixer output is amplified by RF amplifier Q101 and applied to varactor-tuned filter circuits, amplified by Q102, applied to another varactor-tuned filter circuit and then applied to RF amplifier/ALC attenuator Q108, CR110 and CR111. The automatic level control (ALC) from the power amplifier/power supply 1A5 is a control voltage to reduce transmitter output should an abnormal visual standing wave ratio (VSWR) condition occur on the antenna/transmission line.

The varactor-tuned filters in both the transmit and receive paths are controlled by a tuning voltage developed by frequency synthesizer 1A1 as previously discussed. This voltage is further processed by the tuning voltage converter Q1-3 and CR1-9. (See fig. 1-16.) As shown in figure 1-16, the tuning voltage from synthesizer 1A1 increases almost linearly with frequency. At 300 MHz, the voltage characteristic repeats itself, since this is the frequency at which the RF output signal becomes the result of sum mixing. The tuning voltage converter reshapes the tuning voltage as shown in the figure.

The output of RF AMP/ALC attenuator Q108 is a frequency 225- to 399.975-MHz (as selected by the control unit) amplitude-modulated signal which goes to power amplifier/power supply module 1A5 for amplification and transmission.

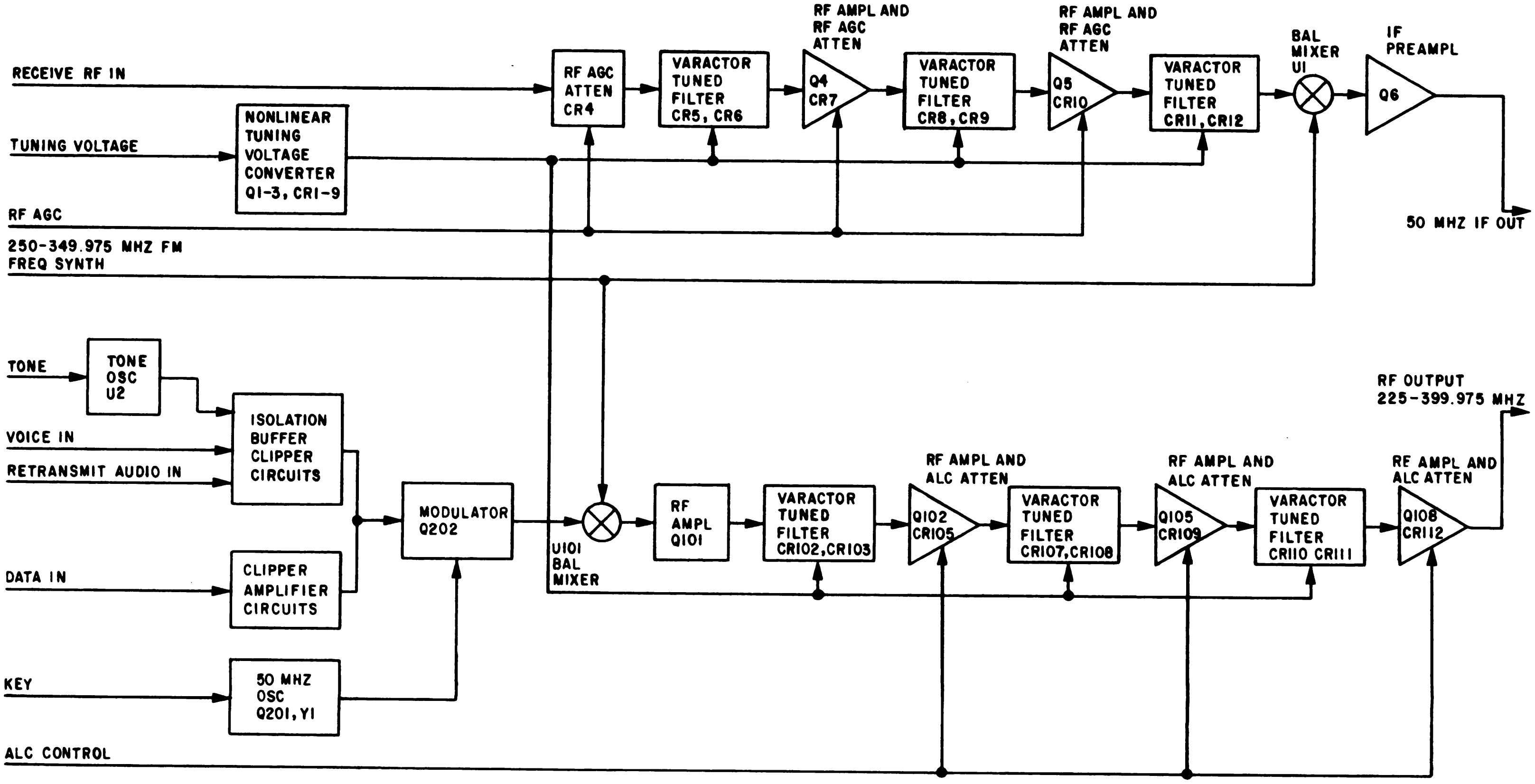

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Figure 1-15.—RF Translator/Modulator 1A2 block diagram.

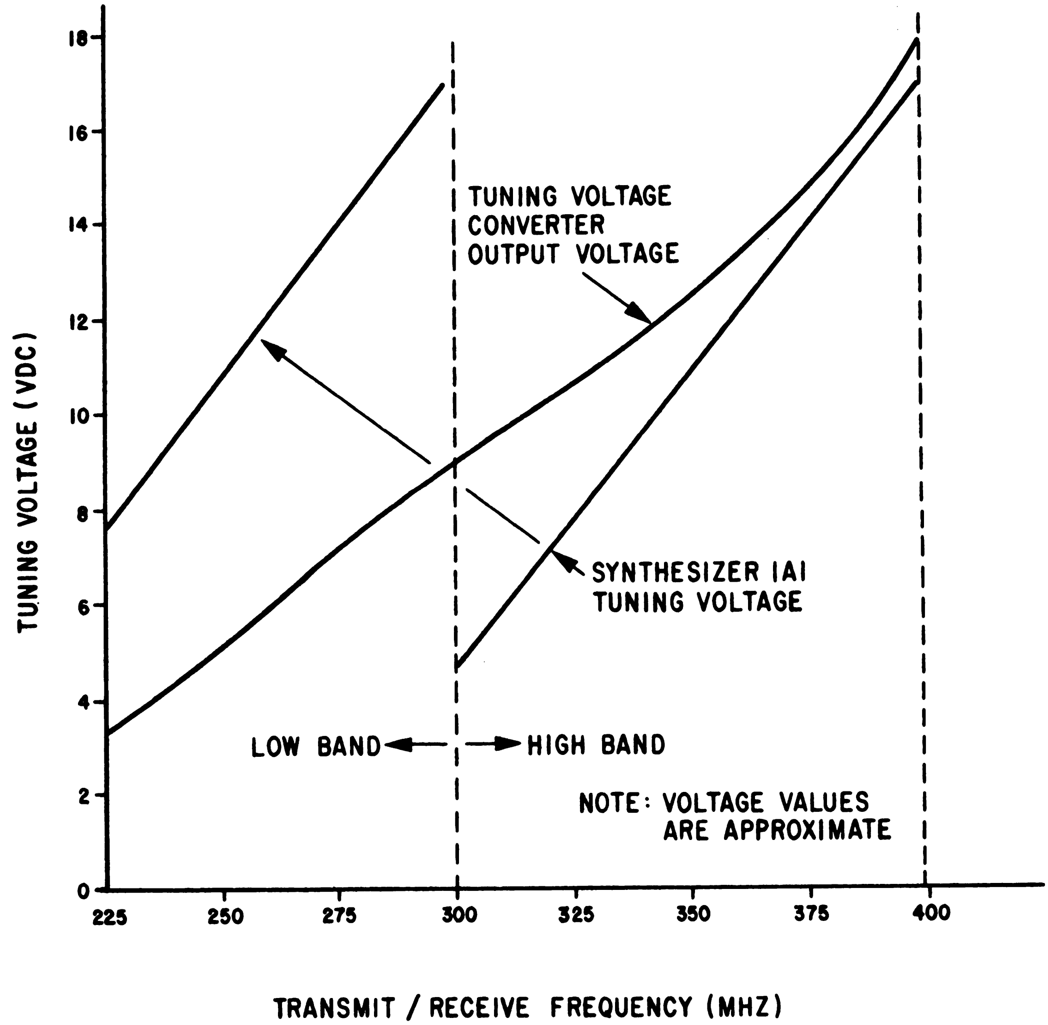

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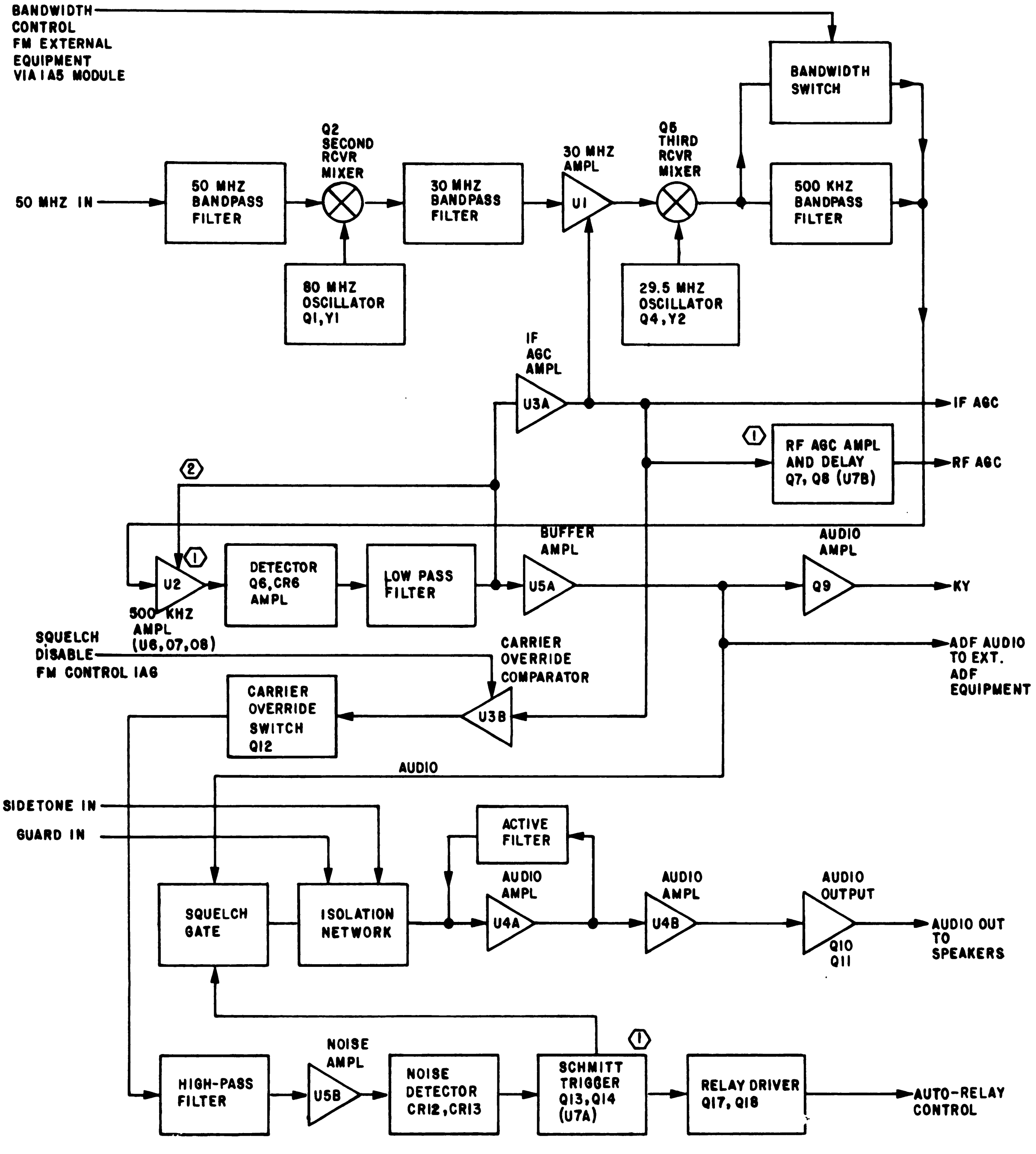
Figure 1-16.—Radio Set AN/ARC-159, RF Translator/Modulator 1A2, Frequency vs Tuning Voltage.

In the receive mode, the incoming signal, which comes from power amplifier/power supply 1A5, is applied through RF AGC (automatic gain control) CR4, through varactor-tuned filter CR5, CR6 to RF amplifier/AGC attenuator Q4, CR7. The AGC voltage is developed by IF/audio module 1A3 and will be discussed later. The signal is amplified by Q4 and Q5 and applied to balanced mixer U1. In the mixer the incoming signal is mixed with the injection signal from the frequency synthesizer 1A1 to produce the 50-MHz first IF (intermediate frequency). The 50-MHz IF signal is amplified by Q6 and routed to IF/audio amplifier module 1A3.

IF/AUDIO AMPLIFIER 1A3.—In the receive mode, the IF/audio amplifier 1A3 (fig. 1-17) provides frequency translation, bandwidth control, detection, and amplification for the main receiver. It also provides audio amplification for the guard receiver 1A4.

The 50-MHz audio-modulated received signal from the RF translator/modulator 1A2 is applied through the 50-MHz bandpass filter to the second receiver mixer Q2. In the mixer the



NOTES:
① COMPONENTS IN (PARENTHESIS) APPLY TO 1A3, 608-9420-003 ONLY.
② CONNECTION FROM U3A TO U2 APPLIES TO 1A3, 608-9420-002 ONLY.

228.172

Figure 1-17.—IF/audio amplifier 1A3 block diagram.

50-MHz signal is mixed with 80-MHz crystal-controlled oscillator (Q1, Y1) signal. The resulting 30-MHz signal output is applied through a 30-MHz bandpass filter and amplified to the third receiver mixer Q5. In the mixer the 30-MHz signal is mixed with the 29.5-MHz signal from xtal-controlled (crystal-controlled) oscillator Q4, Y2. The resulting 500-kHz output signal is applied to the 500-kHz bandpass filter in narrow (normal) band mode of operation. In the wide-band mode (secure voice/data/ADF inputs) a ground is applied to the bandwidth switch from external equipment via 1A5 module, allowing the 500-kHz signal to by-pass the 500-kHz filter. The 500-kHz signal is amplified by U2 and is demodulated by diode detector CR6. Detected audio is amplified by Q6, and fed to a low-pass filter. Out of the low-pass filter, a portion of the signal is fed back to 500-kHz amplifier U2 as an AGC voltage. The output of the low-pass filter (audio signal and noise) is applied to buffer amplifier U5A and IF/AGC amplifier U3A. (NOTE: We will come back to the U5A signal after coverage of U3A outputs.)

The output of U3A is applied to 30-MHz amplifier U1 as an AGC voltage, and to the U7B RF AGC amplifier. The U7B's output goes to RF translator/modulator 1A2. The output of U3A is also applied to carrier override comparator U3B. The output of U3B is dependent upon the amplitude of the audio/noise signal and the setting of the squelch control in the control unit 1A6. (See control knob on the front of the equipment in fig. 1-10.) This output is applied to carrier override switch Q12. It is either conducting or nonconducting (squelch on or off) dependent upon the output of U3B. With the squelch functioning, the output of Q12 is applied to a high pass filter, which removes all but the noise component of the signal. This noise is amplified by U5B, detected by CR12 and CR13 and applied to Schmidt trigger circuit U7A. The output of U7A controls the operation of auto-relay switches (used for data link operation) and the squelch gate.

The audio output signal from U5A (buffer amplifier) is applied to three places: to Q9 where it is amplified and is an output to external secure voice equipment, to external ADF equipment, and to the squelch gate. The signal out of the squelch gate is dependent upon the operation of the squelch circuits and is applied to an isolation network. At this point, if the guard receiver is in operation in addition to the main receiver, the two signals are amplified by U4A, U4B, Q10 and Q11 and are an output to an ICS system (intercommunications system, which will be covered later in this chapter), and to the operator's headset or speaker.

You will note also that a third input to the isolation network is sidetone. This input comes from the power amplifier/power supply unit 1A5. It is a sample audio signal of the actual RF transmission (operator's own voice). It too is amplified by U4A, U4B, Q10 and Q11 and applied to the headset during transmission, so the operator's own transmission is audible.

GUARD RECEIVER 1A4.—The guard receiver unit 1A4 (fig. 1-18) is self-contained except for its power supply and final audio amplification which was just discussed. It is fixed tuned to 243 MHz and has the same performance characteristics as the main receiver except for dual-band capability.

The received guard frequency signal (from the T/R switch in the power amplifier/power supply 1A5) is filtered and applied to RF amplifier/AGC attenuator Q2. The 243-MHz signal is amplified, filtered again and applied to first mixer Q6. In the mixer, it is combined with 217.5 MHz from xtal-controlled oscillator Q3 and frequency doubler Q4. The resultant difference frequency output of 25.5 MHz (1st IF frequency) is amplified by Q7, filtered by a 25.5 MHz band-pass filter and applied to amplifier U1. The amplified output is applied to 2nd mixer Q8. In the mixer, the 25.5-MHz signal (audio modulated) is combined with 23 MHz from xtal-controlled oscillator Q5. The resultant difference frequency output of 2.5 MHz (2nd IF frequency) is applied to amplifier U2. The output of U2 is detected by Q9. The audio signal out of Q9 is filtered and is applied to amplifier U4A. Also, the output of filter L28 is applied back to amplifier U2 and AGC amplifier U3A as an AGC voltage. U3A amplifies the AGC voltage, and its output is applied to U1, U3B

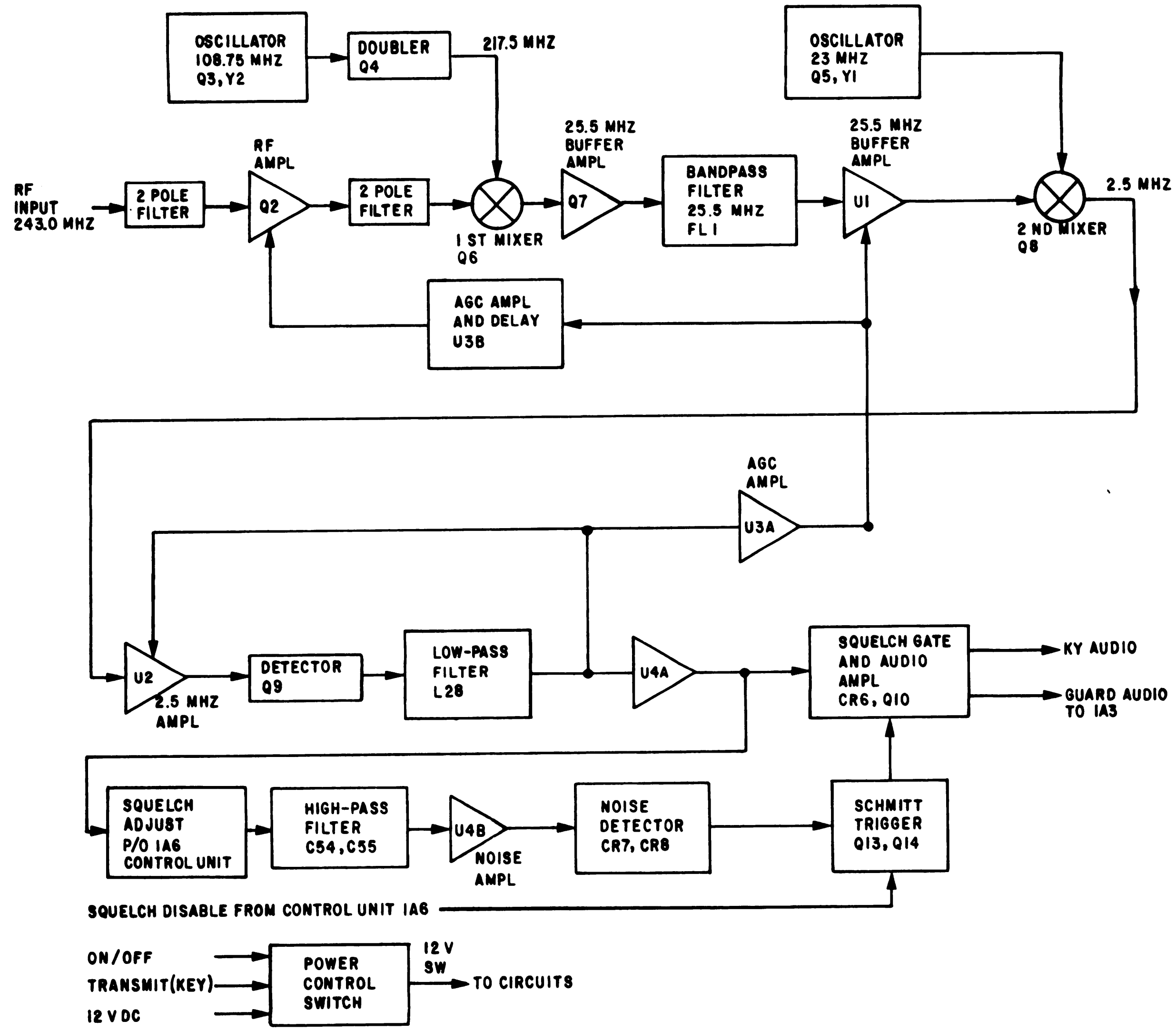


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Figure 1-18.—Guard receiver 1A4 block diagram.

and to Q2. The output of U4A is applied to squelch gate and audio amplifier CR6 and Q10, and to the squelch circuits. The squelch circuits operate the same as those previously described for the 1A3 unit. The audio output signal from Q10 goes to IF/audio amplifier (guard audio) and to external secure voice equipment (ky audio).

POWER AMPLIFIER/POWER SUPPLY 1A5.—When the radio set is keyed (transmit mode) low-level modulated RF from the RF translator 1A2 is applied to a broad-band linear amplifier. (See figure 1-19.) The output is then applied to a broad-band power amplifier which amplifies the signal to the final 10-watt (carrier) output level. The high-level signal is then applied through a 400-MHz low-pass filter, directional coupler, and a T/R (transmit/receive) switch to the antenna.

Forward and reflected power dc analog voltages are developed in the directional coupler during transmissions. The forward power analog

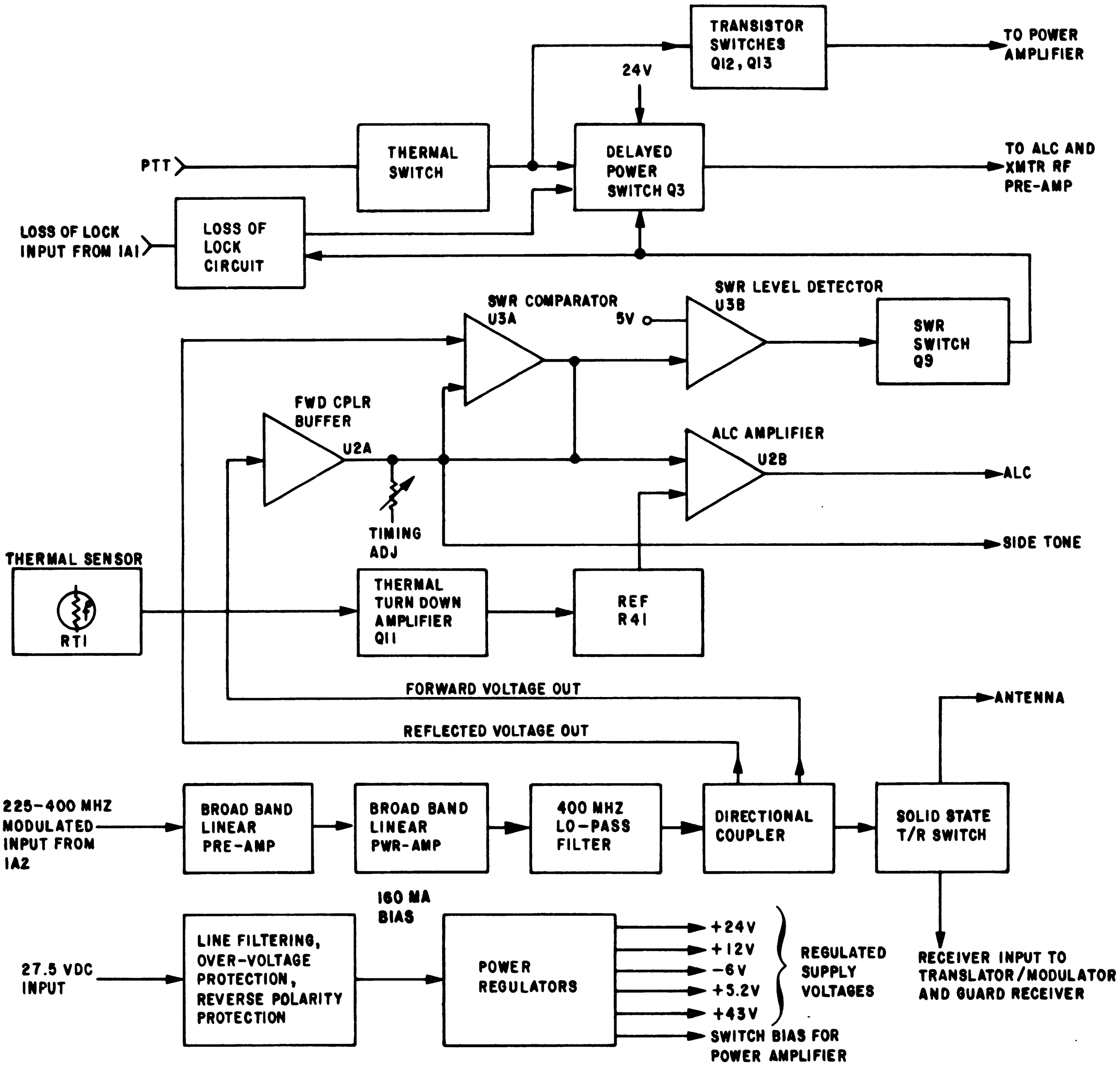

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Figure 1-19.—Power amplifier/power supply 1A5 block diagram.

voltage is buffered by amplifier U2A and applied to the inverting inputs of ALC amplifier U2B and standing wave ratio (SWR) comparator U3A. Also, part of the circuitry of the buffer amplifier detects the audio modulation which is impressed on the RF carrier and this detected audio is applied to the IF/audio unit 1A3 as sidetone so that the operator can monitor his/her own transmission.

The reflected power analog voltage is applied to the noninverting input of SWR comparator U3A, so that the ratio of forward to reflected power is continuously monitored. The outputs of U3A and buffer amplifier U2A are combined and applied to the inverting input of ALC amplifier U2B and to the noninverting input of SWR level detector U3B. In this way, excessive forward or reflected power will lower transmitter output by decreasing ALC voltage applied to RF translator/modulator 1A2 and decreasing the supply voltage applied to the RF preamplifier.

The current through thermal sensor RT1 is directly proportional to equipment temperature. This current develops an analog voltage which is applied to the base of thermal turn down amplifier Q11. As temperature increases, transistor Q11 is driven into conduction to lower the voltage applied to the noninverting input of ALC amplifier U2B. As this voltage (ALC reference) is lowered, ALC voltage out of U2B is decreased to lower the output of the RF translator/modulator 1A2.

When a dc ground is applied to the push to talk (PTT) key line (keying a microphone), transistor switches Q12 and Q13 are biased on to apply 160 mA bias to the power amplifier. At the same time, the delayed power switch Q3 is biased off so that operating voltages are applied to the RF preamplifier through a delaying circuit. The thermal switch in series with the PTT key line opens at approximately 100°C (212°F). If the switch opens, power-amplifier bias and pre-amp voltages are disabled.

To prevent undesired transmission while the frequency synthesizer 1A1 is off frequency (for example rechanneling) a loss-of-lock signal from the synthesizer is applied to the delayed power switch which causes the removal of the RF preamplifier operating voltages.

Primary power +27.5 V dc is applied to the power supply. The power supply regulates the input voltage to 24 V dc and has six output voltages which supply the electronic circuits with all required operating voltages.

CONTROL UNIT 1A6.—Voltage is applied to the binary-coded decimal (BCD) control lines through pull-up resistors R6, R7, R8 and R9.

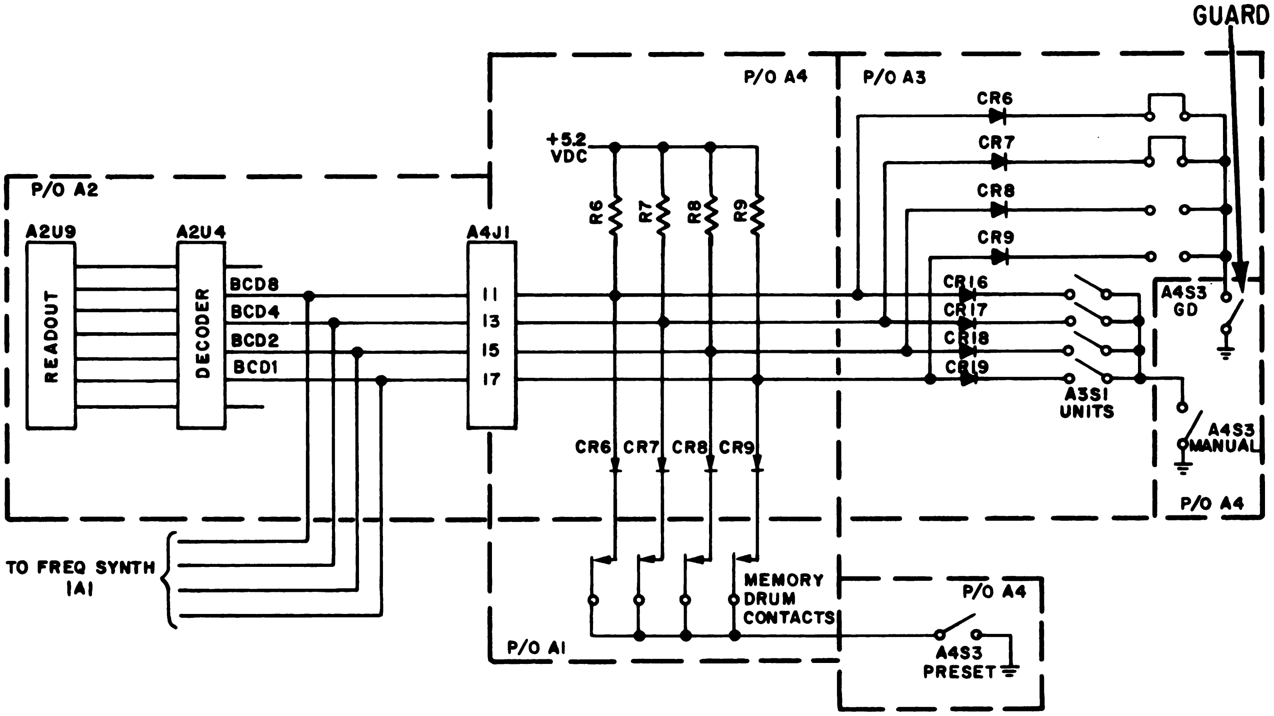

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Figure 1-20.—Control unit 1A6, units circuit, simplified diagram.

(See fig. 1-20.) If the mode selector switch A4S3 is set to MANUAL, units switch A3S1 determines BCD coding by applying dc ground to selected lines. In PRESET mode, grounds are applied to the BCD lines through the memory drum contacts. If guard mode is selected, grounds are applied to the BCD "4" and "8" lines to set those lines at logic "0." The BCD "1" and "2" lines remain at logic "1" to control the units or 3-MHz digit of the 243.00 MHz-guard frequency.

The BCD control lines are routed to the frequency synthesizer 1A1 and to decoder A2U4. In the decoder, the BCD coding is translated to control 7-bar readout A2U9 (readout on front of unit).

OVERALL SYSTEM FUNCTIONAL THEORY.—(See fig. 1-13 and 1-21.) Received signals from the antenna are routed through the solid state transmit/receive switch in the power amplifier/power supply unit 1A5 to RF translator/modulator unit 1A2 and guard receiver unit 1A4. The RF translator/modulator receive section consists of varactor-tuned filters and a balanced mixer that converts the received signal to a 50-MHz IF signal. Tuning voltage for the varactor-tuned filters and the injection signal

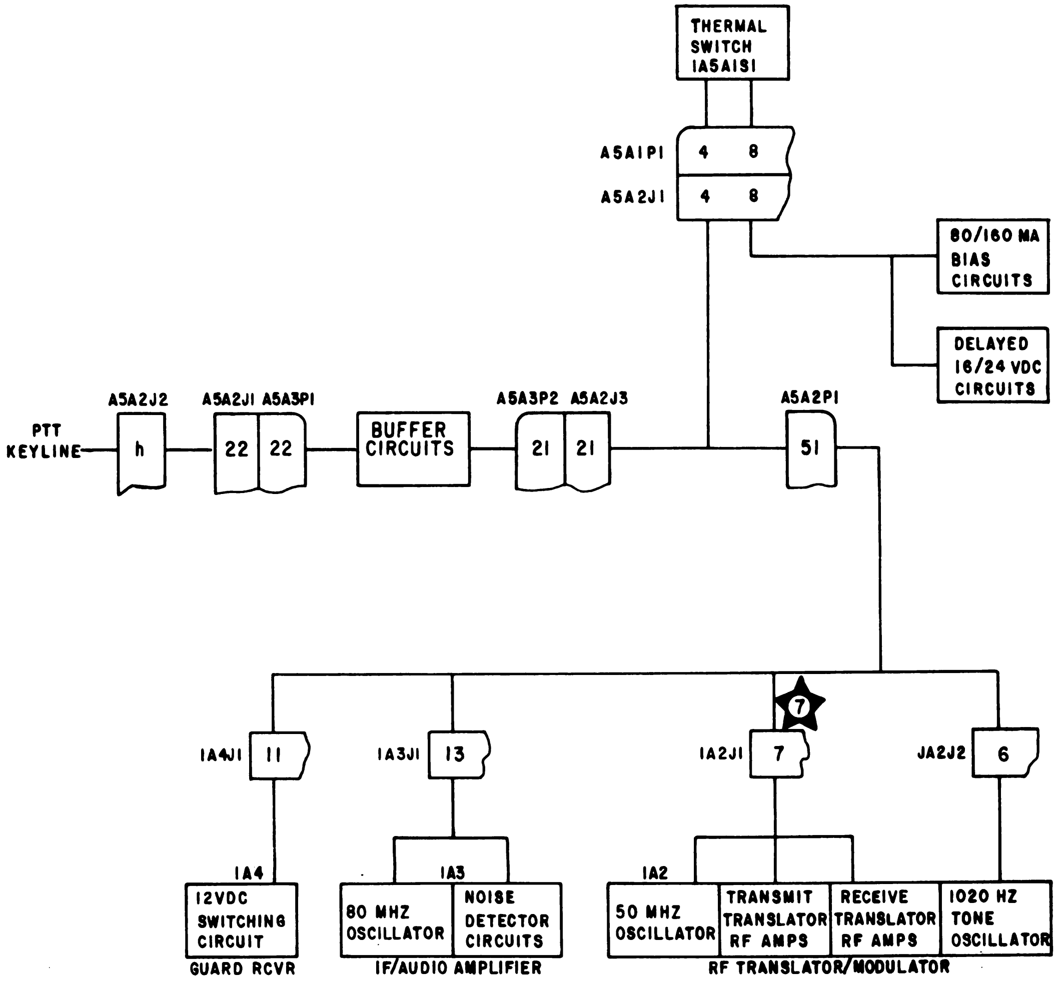

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Figure 1-21.—Keying circuit (PPT) simplified diagram.

for the mixer are provided by frequency synthesizer unit 1A1.

The 50-MHz IF signal from the first mixer is applied to IF/audio unit 1A3, where it is amplified and converted to 30 MHz. The 30-MHz second IF signal is then amplified, converted to 500 kHz, and applied to the detector. Detected audio is amplified and routed to the voice, ADF, and wide-band outputs.

In transmit mode, the injection signal from the frequency synthesizer 1A1 is mixed with the modulated output of a 50-Mhz crystal-controlled oscillator in RF translator/modulator 1A2 to produce the desired transmit frequency. Varactor-tuned filters provide selectivity for the low-level RF transmit signal. The signal is amplified to a 10-watt carrier level by two broad-band linear power amplifiers in power amplifier/power supply 1A5.

Control unit 1A6 contains frequency, mode, and control selectors. In addition, it contains a 20-channel preset mechanical memory drum and an electronic readout assembly. When a frequency is selected, parallel binary-coded decimal-frequency-control information from the control unit is applied to the frequency synthesizer 1A1.

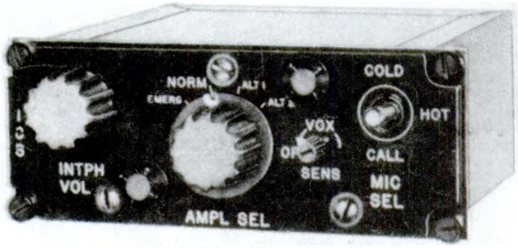
When a dc ground is applied to the PTT (push to talk) key line, operating voltages are applied to RF amplifier circuits in power amplifier/power supply 1A5. (See fig. 1-21.) At the same time, the transmit/receive switch is set to the transmit position.

In the RF translator/modulator 1A2, a dc ground on the PTT key line disables receive circuits and switches mixer injection from the receive mixer to the transmit mixer. At the same time, transmit RF amplifiers and the 50-MHz oscillator are enabled.

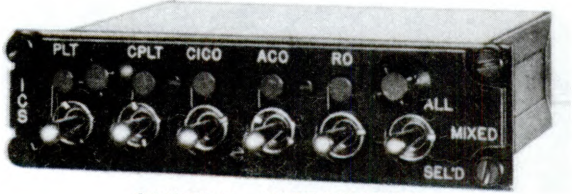
A dc ground applied to the PTT key line also disables the 80-MHz oscillator in the IF/audio amplifier 1A3 and disables supply voltage to the guard receiver 1A4. The power amplifier is protected by a thermal switch in series with the PTT key line. If power amplifier heat-sink temperature exceeds 100°C, the thermal switch opens to disable transmitter operating voltages.

INTERCOMMUNICATION SYSTEMS

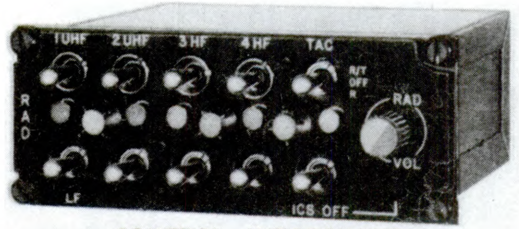
All aircraft intercommunication systems perform essentially the same basic functions. They deliver audio to one or more selected stations on board the aircraft to permit crewmembers to speak to each other. They also provide control of the communication facilities so that various members of the crew may receive incoming radio messages or initiate messages with the aircraft transmitters. It is also often necessary that the intercommunication system contain facilities for operating recording equipment so that permanent records may be made of the various receptions and transmissions occurring during flight.



CONTROL, INTERPHONE
C-2645D/AIC-14A



CONTROL, INTERPHONE
C-4951/AIC-14A



CONTROL, INTERPHONE
C-4949/AIC-14A

228.177

Figure 1-22.—AN/AIC-14A components.

It is not possible in the scope of this discussion to describe all types of intercommunication systems installed in naval aircraft. We will utilize the A1C-14A to show characteristics common to most installations.

INTERCOMMUNICATIONS SET A1C-14A

The A1C-14A is an intra-aircraft communications system designed to provide high-intelligibility communications under all of the conditions encountered in modern military aircraft. It provides two-way amplified voice communications between aircrew stations, and integrates all of the aircraft's communications equipment. The system is based on modular control panel concepts and provides a high degree of versatility. There are a variety of individual components and subassemblies available for use with and within the system, to permit adaption of the basic system to various aircraft. The most common installation utilized in modern aircraft today consists of three control interphone units. These units are shown in figure 1-22.

Control Interphone C2645D/A1C-14A

Control interphone C2645D/A1C-14A (see fig. 1-23) is the master control unit for the system, and is located at all manned interphone crew stations. It contains two transistorized plug-in amplifier modules. In normal operation, one amplifier (isolation) is utilized for amplifying and isolating INCOMING communications equipment and interphone audio, and the other (interphone) provides the amplification and isolation necessary for all OUTGOING audio (from the station's microphone). The audio level of the isolation amplifier (incoming audio to the headset) is set by INTPH VOL control. (#1, fig. 1-23.) The modes of operation (function of the amplifier) are controlled by AMPL SEL control. (#2, fig. 1-23.) Should one of the amplifiers fail, one amplifier will perform the combined operation of the two, but in that case only the cold MIC (will be explained later in this chapter) mode of operation can be utilized. Should both amplifiers fail, the AMPL SEL control can be set to the EMERG position giving the operator control over the communications equipment (TX/RX) but no ICS (Intercommunications System) audio is available between crew stations.

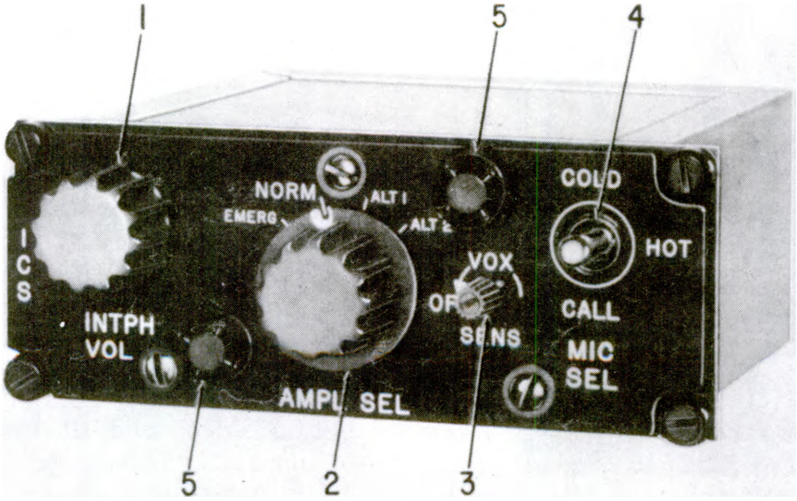


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Figure 1-23.—Control Interphone C-2645D/AIC-14, Front Panel.

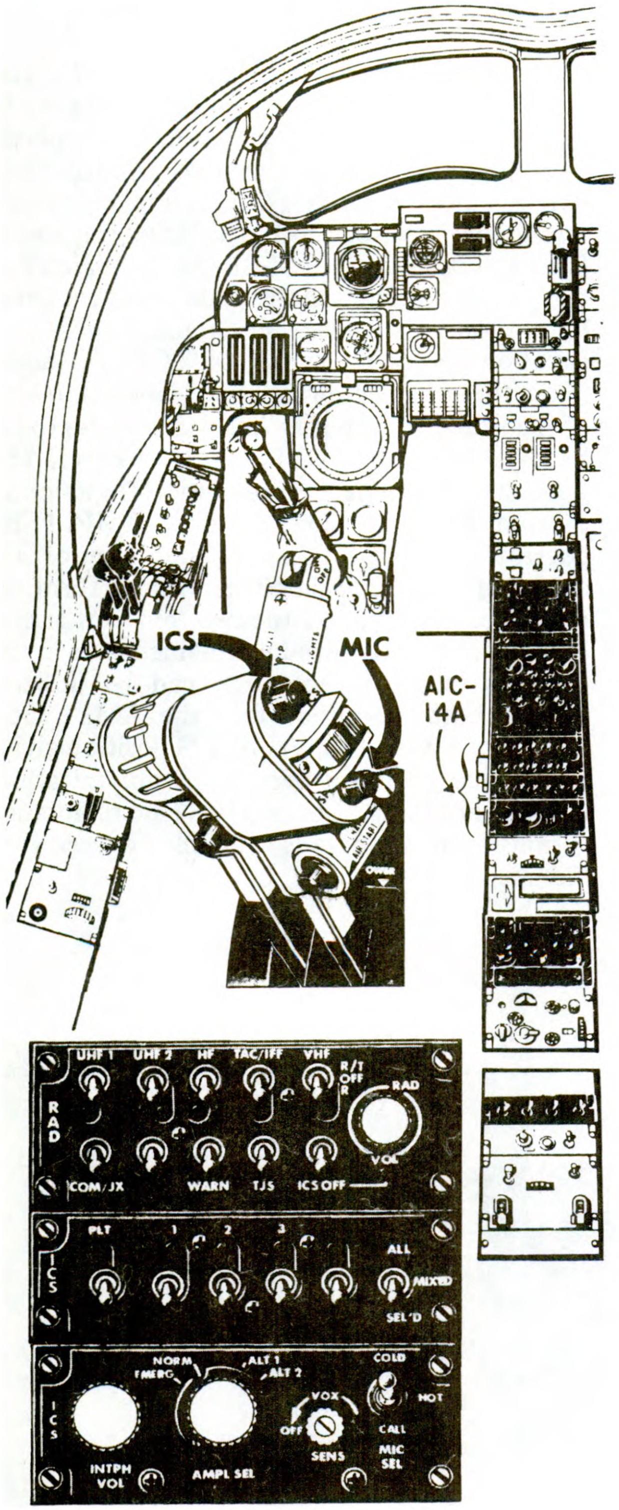

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Figure 1-24.—Typical pilot's ICS controls configuration.

There are two types of microphone control available with the system. In the cold position of the MIC SEL switch (#4, fig. 1-23), a microphone key button must be depressed before the operator can speak over either the ICS or communications transmitters. (There are two key buttons; one for ICS and one (MIC) for the communications transmitters.) Figures 1-24 and 1-25 show a typical location of these switches as well as the installation of the system control units. In the HOT position of the MIC SEL switch, the microphone keying is controlled by the operator's voice. The voice level at which the microphone is keyed is determined by the setting of the VOX (voice operated transmit) control. (#3, fig. 1-23.) The third position of the MIC SEL switch (CALL) is a spring-loaded position used to override all other station's ICS control box selections made on interphone control/ C-4951/AIC-14A, which will be covered next.

Panel lights which light up all lettering for night flying are shown as #5 on figure 1-23.

Control Interphone C-4951/AIC-14A

Control Interphone C-4951/AIC-14A (see fig. 1-26) is used in conjunction with the C-2654D to control the operator's ICS microphone and incoming audio to the operator's headset. It contains five individual-station 3-position toggle switches (#1, fig. 1-26) and a 3-position ALL-MIXED-SELECTED switch. (#3, fig. 1-26.)

In the ALL position when the ICS key button is selected the operator will talk to all stations except those which have the ICS turned to OFF. (NOTE: The ICS on/off control is located on the C-4949/AIC-14A interphone control. It will be discussed later.) The operator can also monitor all incoming stations at once.

In the MIXED position when the ICS key button is depressed, the operator will only talk to those stations selected on switches (#1, fig. 1-26). However, the operator is still simultaneously monitoring all stations trying to call in. In the SEL'D position, when the ICS key button is depressed the operator can only talk to

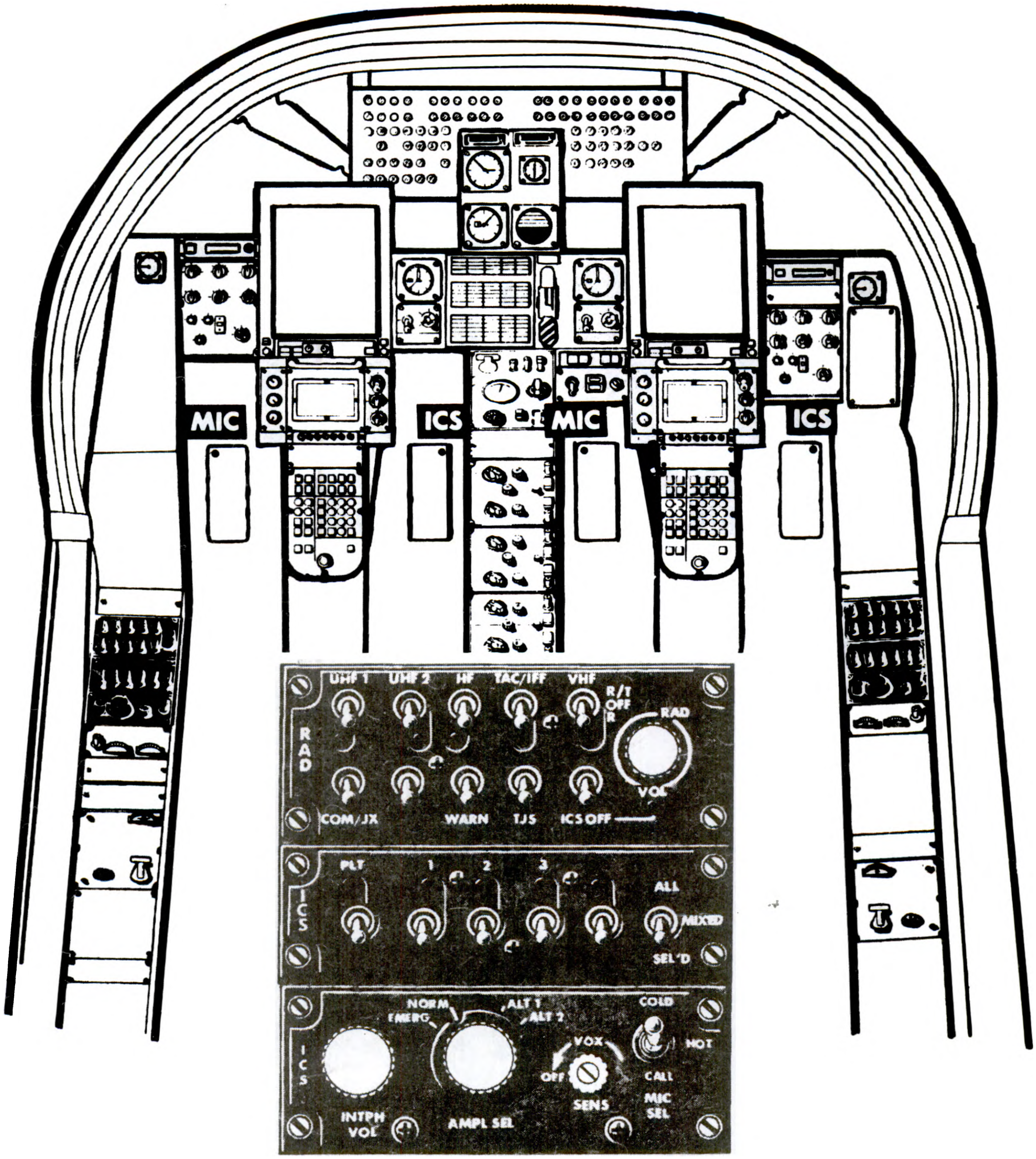

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Figure 1-25.—Typical crew station ICS controls configuration.

those stations which the operator has selected on switches, (#1, fig. 1-26) and can only hear those stations selected. The one exception to this is that any station using the CALL selection (ICS override) on the C-2645D will get through.

The five station switches (#1, fig. 1-26) are 3-position toggle switches. The center position is the "off" position. In the up position ICS communication is established in accordance with the ALL-MIXED-SEL'D switch. In the

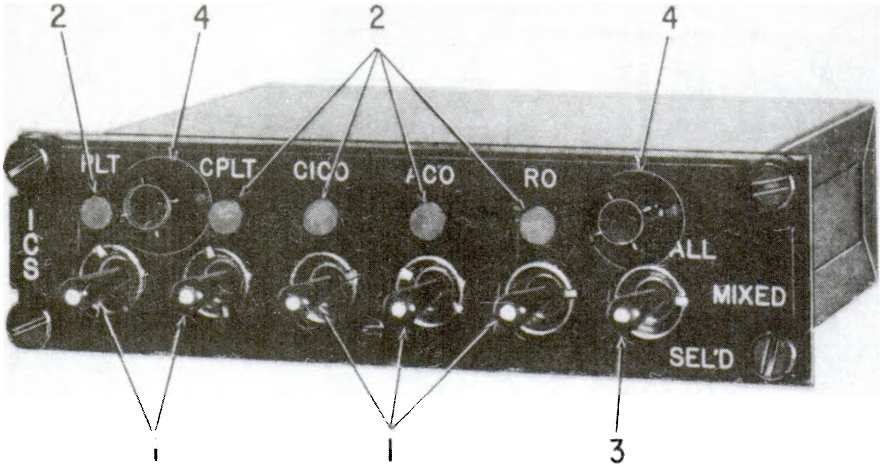

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Figure 1-26.—Control Interphone C-4951/AIC-14A.

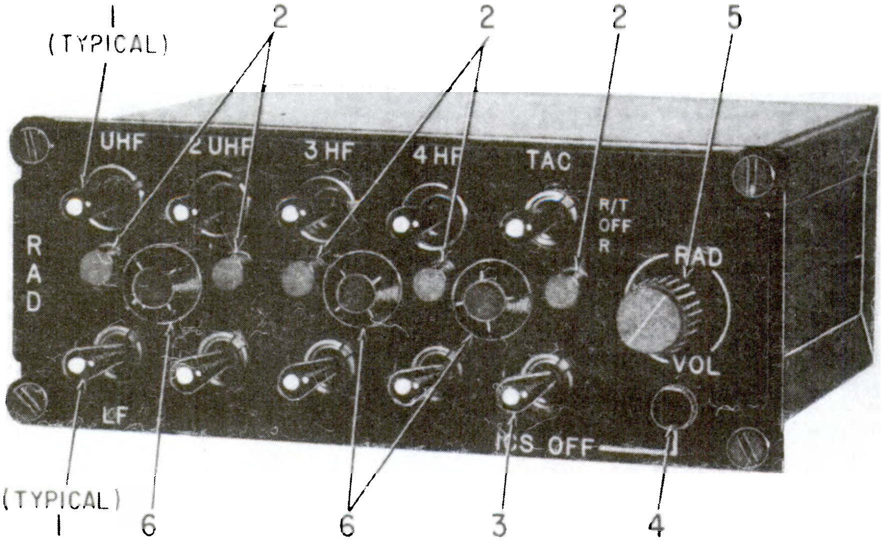

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Figure 1-27.—Control Interphone C-4949/AIC-14A.

down position (spring loaded), the operator can monitor a particular station to see if it is busy and, at the same time, light that station's call light (#2, fig. 1-26) to let the station know someone is trying to call, and who it is.

Control Interphone C-4949/AIC-14A

Control Interphone C-4949/AIC-14A (see fig. 1-27) is used in conjunction with the C-2645D to control the communications receiver audio and transmitter microphone. It contains eight 3-position toggle switches, an ICS ON/OFF switch, and an audio volume control.

The top five radio control switches (#1, fig. 1-27) are used to control the aircraft's receiver/transmitters. The down position of the switch enables the operator to monitor a selected receiver. In the up position (only one at a time), the operator's microphone is connected to the selected transmitter when the MIC key button is depressed, and the operator can monitor the receiver. If more than one of the five switches are in the up position at the same time, the switch to the left has priority. As an example, if the operator has the 2-UHF (see fig. 1-27) switch and the 3-HF switch both in the up position, both receivers will be heard; but when the MIC button is depressed, the microphone will be connected to the 2-UHF transceiver.

The center position of all eight radio control switches is the OFF position.

The bottom four radio control switches (from left to right) allow the operator to monitor various receivers in both the up and down positions. There is no microphone connection to these switches.

Item #2 (fig. 1-27) shows five indicator lamps for the top five radio control switches. Whenever the operator keys a particular transmitter, the indicator lamp lights at all crew stations signifying that particular transmitter is in use.

The ICS ON/OFF switch enables the operator to disconnect from the ICS while communicating on one of the communication's transceivers. (NOTE: The call position of the C-2645 MIC SEL switch overrides this disconnect.)

Item #4 (fig. 1-27) is an indicator light which lights to remind the operator that the set is disconnected from the ICS.

Item #5, the RAD VOL control, allows the operator to adjust the audio level of the eight receivers.

Item #6 shows panel lights which illuminate the lettering on the control box for night flying.

Figure 1-28 is a block diagram depicting the interconnection of the control interphone units.

COMMUNICATION ANTENNAS

An antenna is a special type of electrical circuit intentionally designed to radiate and/or receive electromagnetic energy. In an ordinary circuit, the inductance, capacitance, and resistance are lumped constants and therefore the electromagnetic field is confined to the circuit where it performs useful work. In an antenna, the L, C, and R properties are distributed and the electromagnetic field is not confined; it is spread out and tends to escape or radiate. It is this radiated field which provides the link between a transmitter and receiver.

The method of propagation is of interest; but of more concern to the technician is how the energy can be directed (the radiation pattern) and concentrated (the beamwidth), and how the efficiency (gain) can be enhanced. A familiarity with the basic types of antenna systems and the polarization of the transmitted wave provides a background of information and an appreciation of the problems involved in the selection of a suitable antenna type for a specific application.

Several of the more common antenna configurations with typical operating frequency ranges and radiation patterns are shown in figures 1-29 and 1-30. These figures should be consulted throughout the discussions which follow. Table 1-3 lists the normal polarization and directional characteristics of certain antenna types.

While the simplest type of antenna is the bidirectional dipole, limitations in directivity, frequency passband, and gain somewhat restrict its use. Other dipole configurations such as the ram's horn and the corner reflector are used for special applications.

Although the crossed dipole, the whip, the top-loaded vertical, or the "J" are sometimes used, the ground plane antenna is probably the most popular when reception or transmission must be equally effective in all directions

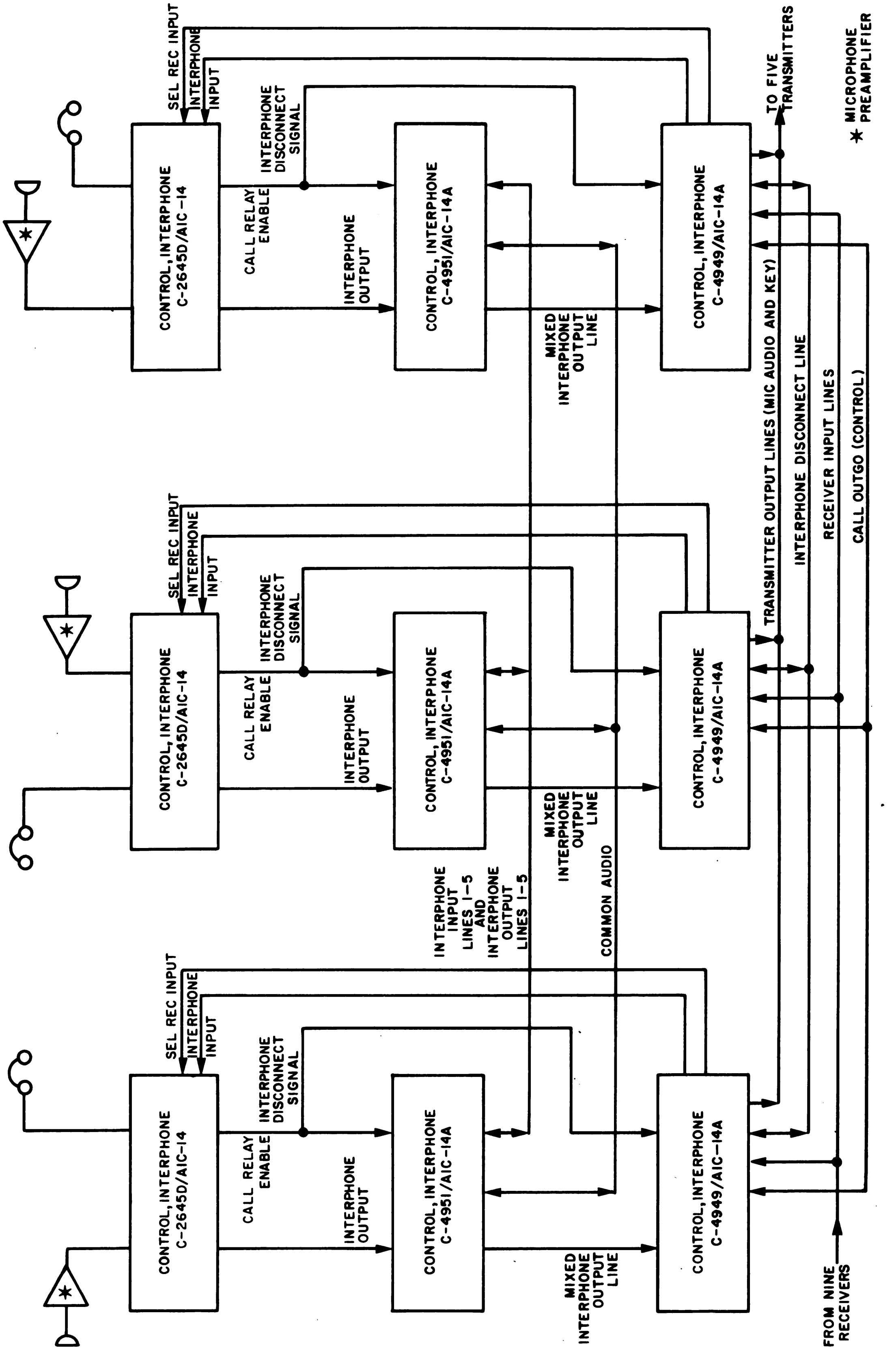
CONTROL, INTERPHONE C-2645D/AIC-14
CONTROL, INTERPHONE C-4951/AIC-14A
CONTROL, INTERPHONE C-4949/AIC-14A
SEL REC INPUT
INTERPHONE INPUT
INTERPHONE DISCONNECT SIGNAL
CALL RELAY ENABLE
INTERPHONE OUTPUT
MIXED INTERPHONE OUTPUT LINE
INTERPHONE INPUT LINES 1-5 AND INTERPHONE OUTPUT LINES 1-5
COMMON AUDIO
TRANSMITTER OUTPUT LINES (MIC AUDIO AND KEY)
INTERPHONE DISCONNECT LINE
RECEIVER INPUT LINES
CALL OUTGO (CONTROL)
TO FIVE TRANSMITTERS
FROM NINE RECEIVERS
* MICROPHONE PREAMPLIFIER

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Figure 1-28.—Intercommunications System AIC-14A, basic typical installation block diagram.

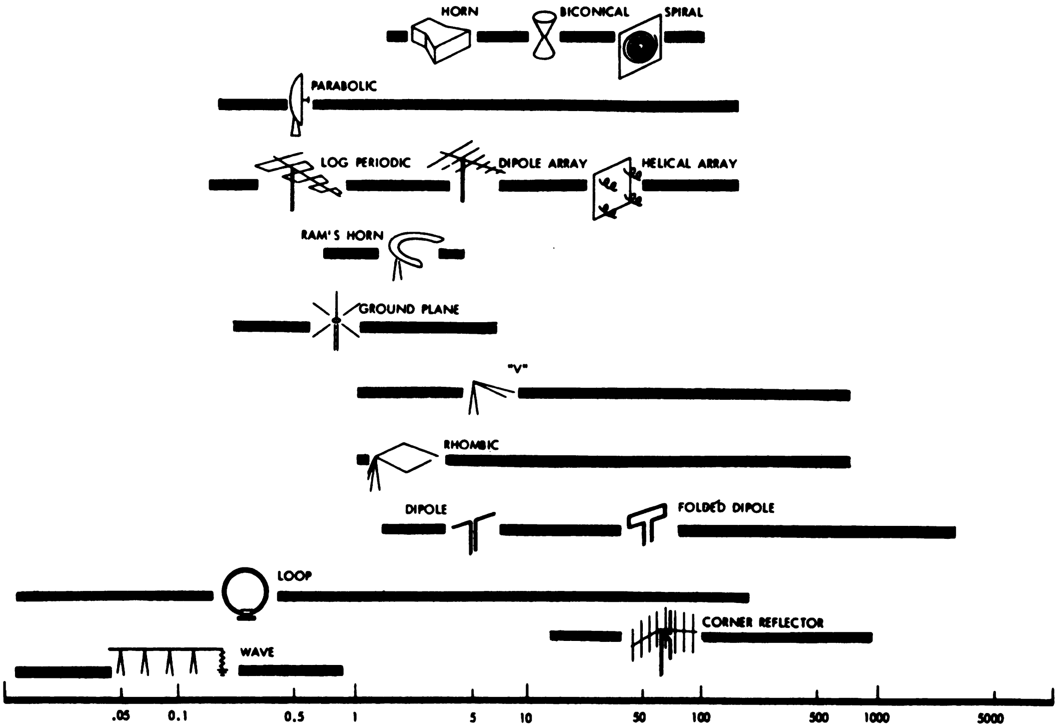

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Figure 1-29.—Antenna selection based on typical operating frequencies in megahertz.

Table 1-3.—Antenna characteristics

Type	Usual polarization	Directivity
Dipole	Horizontal	Bidirectional
Dipole array	Horizontal	Unidirectional
Ground plane	Vertical	Omnidirectional
Parabolic	Horizontal	Unidirectional
Horn	Horizontal	Unidirectional
Corner reflector	Vertical	Unidirectional
Helical array	Circular	Unidirectional
Ram's horn	Horizontal	Bidirectional
Rhombic	Horizontal	Bidirectional, unidirectional
Log periodic	Horizontal	Unidirectional
Spiral	Circular	Bidirectional
Loop	Horizontal	Bidirectional
Biconical	Horizontal	Omnidirectional

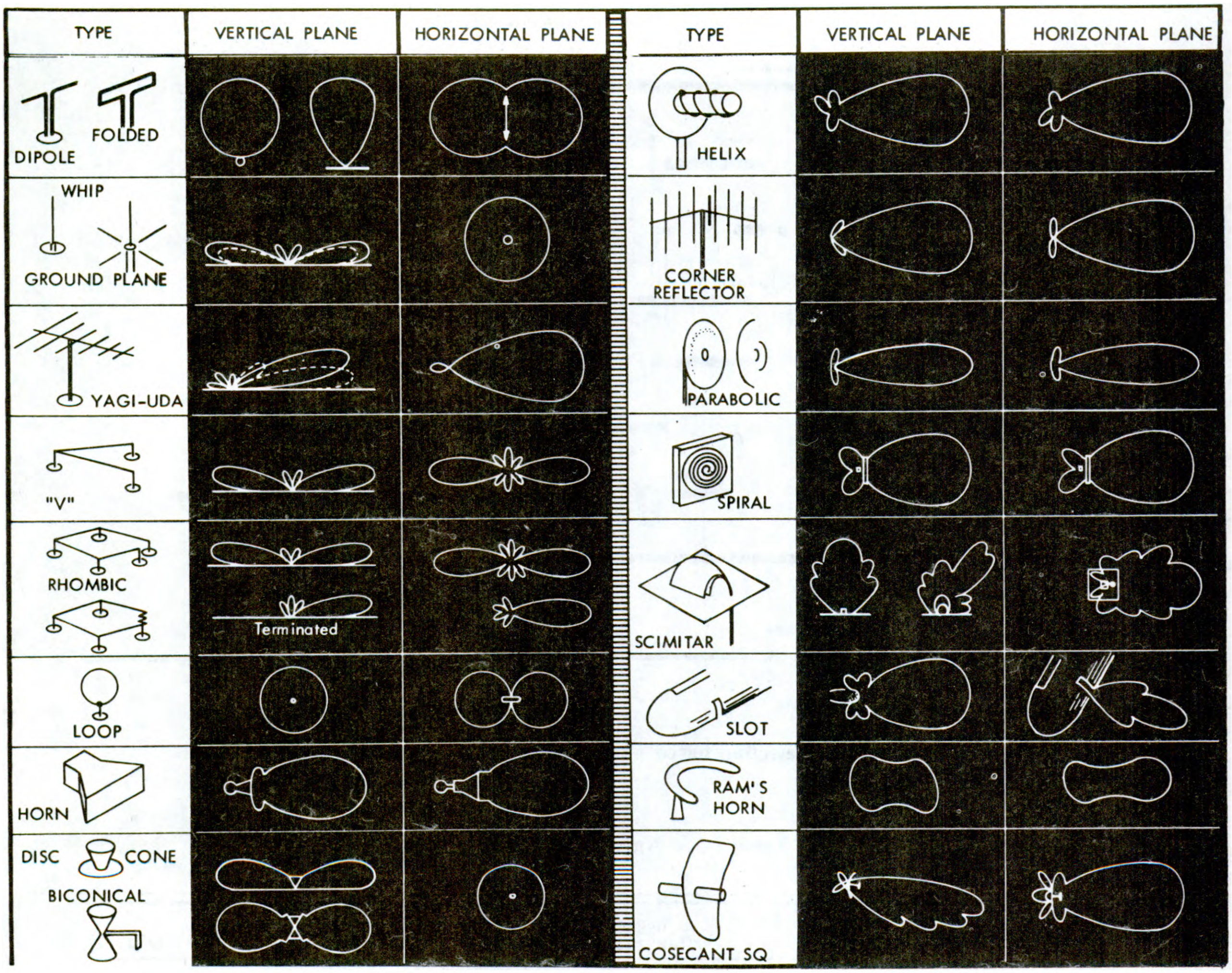

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Figure 1-30.—Typical radiation patterns for selected types of antennas.

(omnidirectional). For much higher frequencies, the biconical or the disk horn is recommended.

The log periodic, helical, and flat-spiral antennas are noted for their extremely wide (as high as 20:1) operating frequency range.

When space is not a controlling factor, the rhombic and the "V" type are often used to provide high gain and directivity. Both types normally are bidirectional. The rhombic can be made unidirectional by terminating the ends of the legs with a noninductive resistor. The "V" is made unidirectional by use of another "V" spaced an odd number of quarter wavelengths behind the original. Typical legs for the rhombic are three to four wavelengths; for the "V" type, legs of eight wavelengths are not uncommon.

The parabolic antenna is capable of producing high gain and excellent directivity. Although screen mesh or even a grid or rods may be used where wind resistance is a design factor, the reflector element generally consists of a solid surface. Physically the reflector should be several wavelengths in diameter. Additional gain also can be obtained by mounting a hemispherical reflector in front of the dipole, provided its surface area does not appreciably shadow the rear parabolic reflector. The radiating element may be a dipole, a horn, or other suitable radiator.

This chapter introduced the communications equipment used on Navy aircraft, including general purpose receivers, HF, VHF, and UHF transceivers, and a typical ICS system. This general overview is designed to help you as you learn to maintain and operate the specific equipment installed on the aircraft to which you are assigned.

CHAPTER 2

AIRBORNE NAVIGATION EQUIPMENT

Airborne navigation equipment is a term which encompasses various equipments and instruments which are used to determine an aircraft's position, altitude and heading. The AT's portion of these equipments include automatic radio direction finders (ADF), VHF omnidirectional range sets (VOR), tactical air navigation sets (TACAN), radar altimeters, long range navigation (loran) sets, Omega navigation sets, instrument landing systems (ILS), marker beacon receiving sets, radar, and identification, friend or foe sets (IFF). NOTE: RADAR AND IFF WILL BE COVERED IN CHAPTER 3.

As an AT, you will be tasked to operate and maintain the various navigation equipments. It is beyond the scope of this manual to teach specific equipments; therefore, only representative equipments will be discussed, to provide you with the basic concepts, capabilities, and operating principles of the various types of navigation sets. Although there may be newer and more sophisticated equipment in use than those depicted as examples in this chapter, keep in mind they all operate on the same concepts as those given here.

AUTOMATIC DIRECTION FINDER (ADF)

An automatic direction finder is a radio receiver equipped with a directional antenna, which is used to determine the direction from which a radio signal is received. The antenna is motor driven by signals from the ADF receiver and is connected by means of servomotors to an indicator pointer (needle). (See figure 2-1.) The pointer will point toward the radio station, giving the operator a relative bearing to the station with respect to aircraft heading. By utilizing a map and knowing the location (city) of the radio station, an ADF operator can determine the aircraft's relative position from the city. By plotting a two-station fix (relative bearings), the operator can determine the aircraft's exact position on the map. (See figure 2-2.)

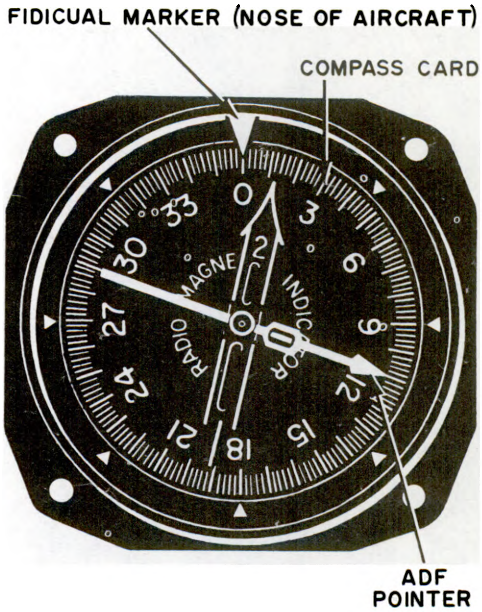

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Figure 2-1.—Typical ADF indicator.

Most ADF units provide for manual operation of the directional antenna (referred to as the loop antenna) in addition to the automatic

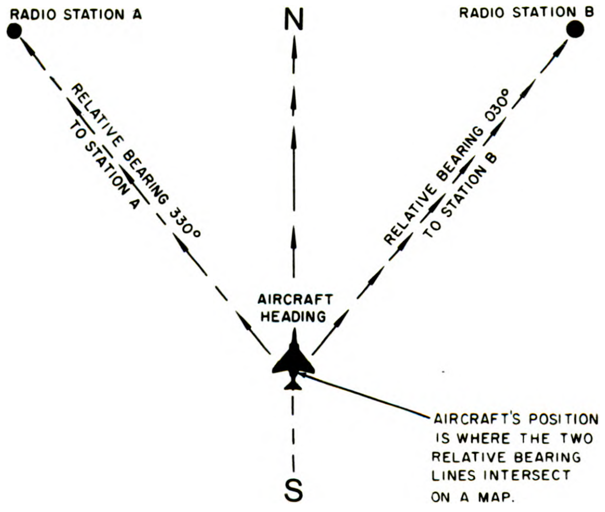

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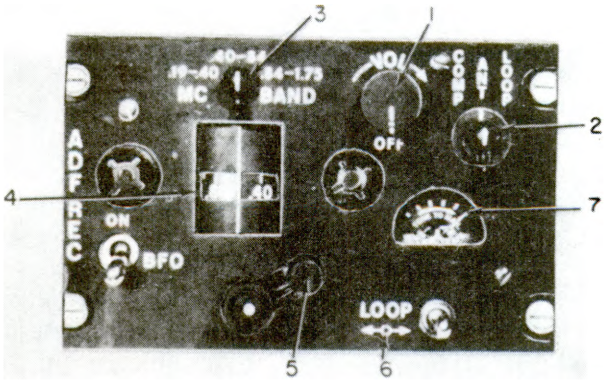
Figure 2-2.—Two-station ADF fix to determine aircraft's position.

mode. The automatic mode involves the use of closed-loop control circuits to operate the antenna; while in manual mode, the operator drives the antenna by use of a control switch located on the ADF control panel. (See figure 2-3.) When the loop antenna is manually tuned for minimum received signal, the indicator pointer will point to the radio station, just as it would in automatic mode.

BASIC PRINCIPLES

When a conductor is cut by magnetic lines of force, or lines of flux, a voltage is induced in the conductor. In order to cut lines of flux, the conductor must be perpendicular or must have a component that is perpendicular to the lines of flux; and the relative motion between flux and conductor must have a component in a direction



CONTROL	FUNCTION
1. OFF/ON Vol	Applies power to equipment and sets headset audio level
2. Mode switch	Selects mode of operation of the equipment Comp—Automatic mode ANT —Selects sense antenna only. Pointer inoperative Loop —Selects loop antenna only
3. Band select	Selects receiver frequency band of operation
4. Frequency dial	Indicates frequency to which the receiver is tuned
5. Tuning knob	Tunes the receiver to desired frequency as indicated by frequency dial
6. Loop switch	Manually drives the loop antenna in the loop mode of operation
7. Signal strength meter	Indicates the amplitude of the received signal

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Figure 2-3.—Typical ADF control panel.

that is perpendicular to both the lines of flux and the conductor.

A vertically polarized wave has a vertical electric (E) field and a horizontal magnetic (H) field; therefore, the wave induces voltage in vertical conductors only. A vertical wire, or monopole, is the simplest type of antenna. When a vertically polarized radio wave induces voltage in a monopole, the induced voltage is in phase with the incident wave and is the same for all horizontal angles of incidence. (See figure 2-4.) This similarity of response pattern, in all directions simultaneously, suggests the name omnidirectional (omni means "all") for this type of antenna.

Loop and Sense Antenna

The response of a loop antenna is different from that of a vertical monopole (called a "sense antenna" in this discussion). A rectangular single-turn loop with dimensions that are small compared to the wavelength of an incident radiation field is shown in figure 2-5A. As the loop is rotated about the XX′ axis, the angle Θ (between the plane of the loop and the direction of propagation of the wave) is changed.

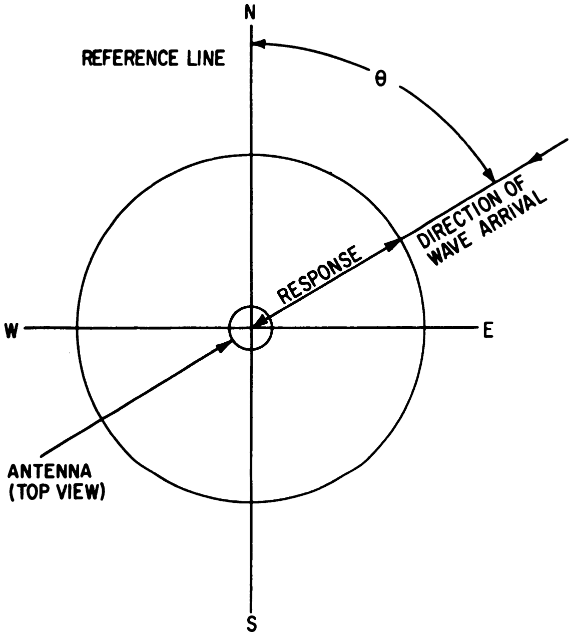

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Figure 2-4.—Polar response of a monopole (sense) antenna.

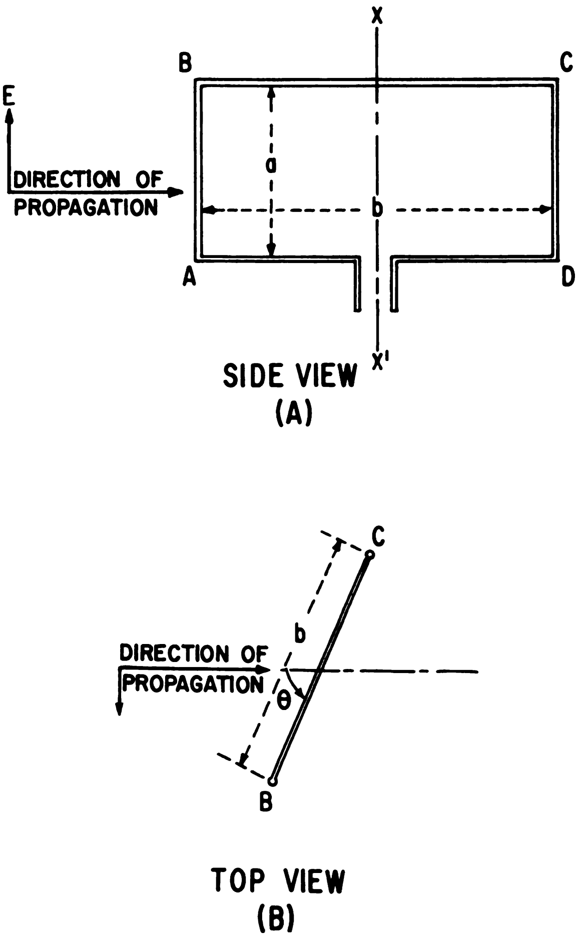

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Figure 2-5.—Loop antenna in a radiation field.

If the loop is placed in the radiation field like the one shown in figure 2-5B, the H vectors of the field cut the sides AB and CD at slightly different times because the wave travels at a finite speed. At any instant, therefore, the voltage induced in arm AB is slightly different from the voltage induced in arm CD. (The arms BC and AD are not affected by the H lines of a wave polarized at right angles to them, and do not contribute to the induced voltage in the loop because the horizontal members are parallel to the H lines.)

If the loop is turned so that its face is perpendicular to the direction of arrival of the wave—that is, $\Theta = 90°$, the sides AB and CD are cut by the H vector at the same instant. The voltages induced in arms AB and CD are then the same magnitude and phase and neutralize each other, so that no current flows in the antenna loop.

Since the magnetic field of the radio wave alternates at the frequency of the wave, the instantaneous flux density at any point along the path of arrival varies sinusoidally. Thus the voltage induced into arms AB and CD are sinusoidal voltages with a phase difference Θ. The total loop voltage is the sinusoidal voltage which represents the integration of the sums of all the instantaneous voltages induced into the two arms. It may be shown mathematically that this resultant voltage is proportional to the cosine of Θ.

The pattern of the response is similar to the figure-of-eight. (See figure 2-6.) All medium-frequency direction-finding equipments obtain bearings by using the response as shown in this figure.

The directional characteristic of the loop antenna is called a cosine, or figure-of-eight pattern. When the loop is oriented so that the received signal is maximum, a small change in orientation produces a small change in signal. However, when the loop is at a null position, a small change in orientation of the loop produces a large change in output voltage. Furthermore, there is a reversal in phase of the signal as the loop passes through a null point. For these reasons, the null points, rather than the maximum-response points, are used in radio direction finding to obtain a line bearing or line of arrival of a radio wave.

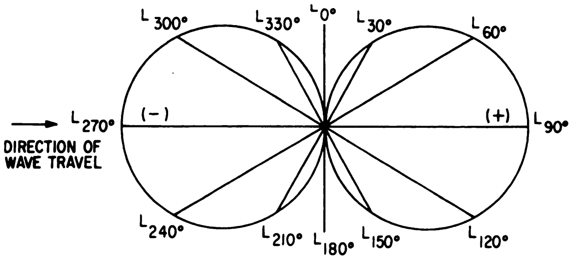

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Figure 2-6.—Polar response of a loop antenna.

As there are two null positions 180° apart, the loop can give a line of bearing (the actual bearing or its reciprocal), but cannot determine the absolute direction of the transmitter from the direction finder. The determination of absolute direction, or sense, is obtained by adding the output of a vertical sense antenna to that of the loop antenna. When the two antennas are properly connected, the combined response is not ambiguous.

Signal Comparison

The figure-of-eight pattern of a loop has two null positions for one incident radio wave (fig. 2-6). If the outputs of a loop and a sense antenna are combined in phase, the response of the two antennas is the algebraic sum of their individual diagrams. In order to produce a given response, the magnitude of the individual signals must be considered. Refer to figure 2-7 for the following discussion.

This figure illustrates four possible responses caused by differences in the relative amplitudes of the sense and loop outputs. The desired response shown in (C) has one sharp null.

The output of the vertical sense antenna is independent of the horizontal direction of arrival of the wave, so it may be considered to have a positive polarity. Because the phase of the loop voltage changes as the loop passes through a null, one-half of the figure-of-eight pattern may be said to have a positive polarity and the other half to have a negative polarity. The addition of the loop and sense curves gives the responses shown. The shape of the resultant curve is called a cardioid because of its similarity to a heart.

The output of the sense antenna is in phase with the radio wave. The output of the loop antenna, however, is 90° out of phase with the radio wave. This means that the loop output voltage is maximum when the sense output is zero and vice versa. The cardioid pattern (which depends on the outputs being in phase) cannot be obtained unless the phase of either the loop or the sense antenna signal is changed by 90°.

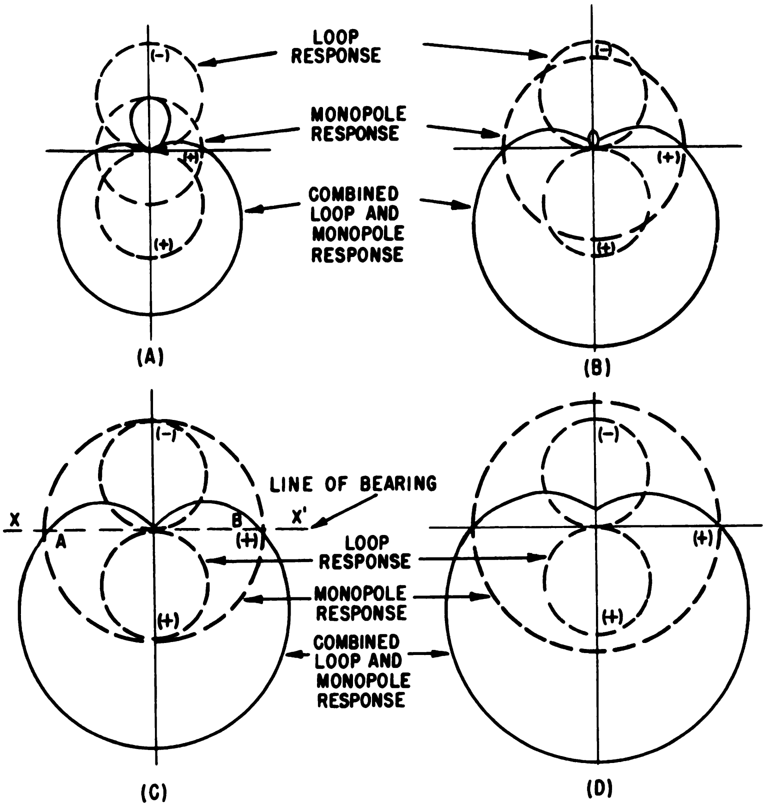

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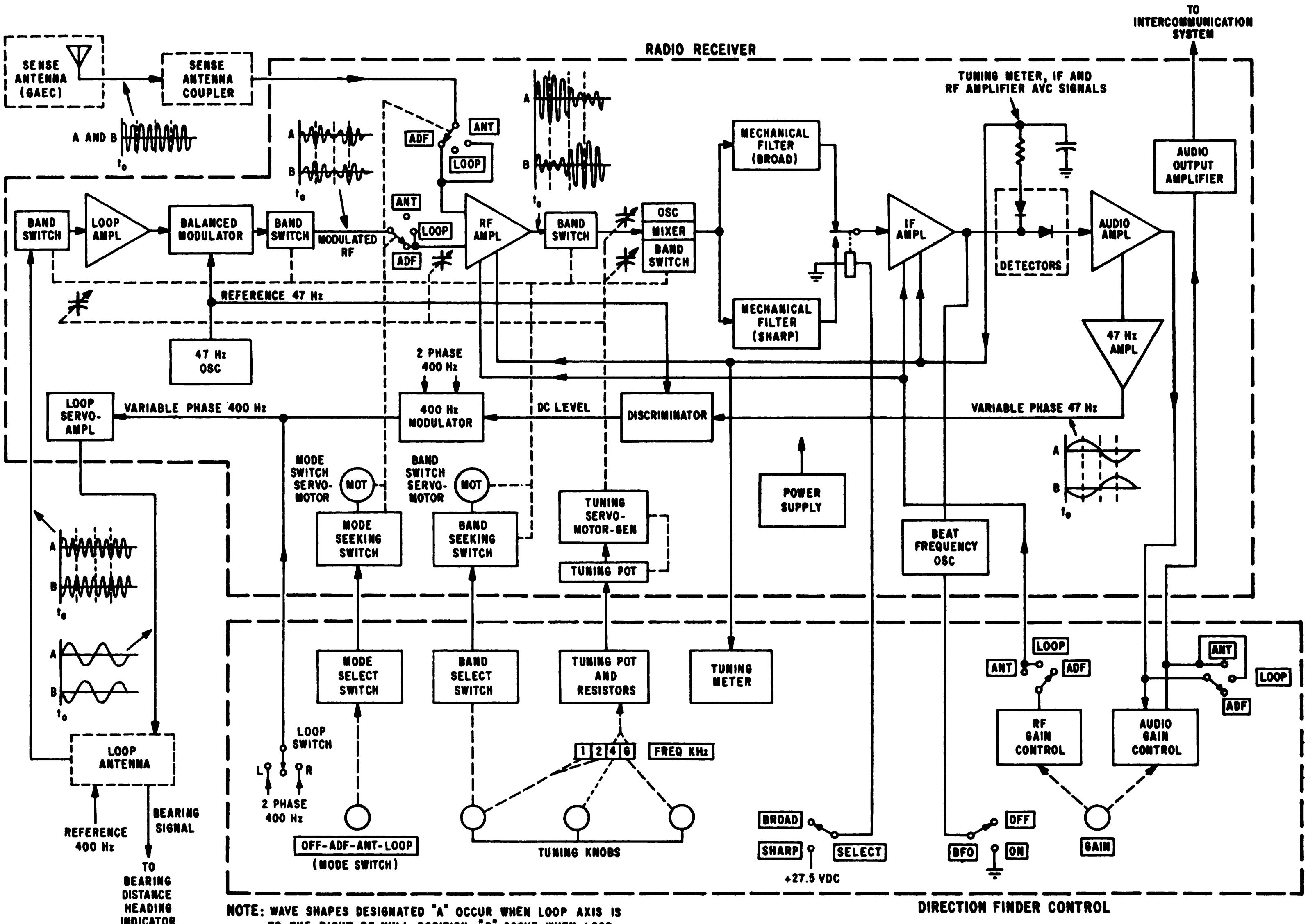
Figure 2-7.—Response of the combined sense and loop antenna.

The cardioid pattern produced by the combined loop and sense antenna can also be produced by a rhombic antenna. This type is used without a sense element.

DIRECTION FINDER SET AN/ARD-13

Direction Finder Set AN/ARD-13 is a low-frequency radio navigation device that operates at frequencies between 90 kHz and 1800 kHz. It is capable of receiving both AM and CW transmissions within its operating range.

The direction finder has three modes of operation which are selected remotely at the control unit. In the ANT mode, the RF input to the receiver is from the sense antenna; the direction finder operates as a nondirectional low frequency receiver. The RF input in the LOOP mode is from the loop antenna. The LOOP mode may be used for manual direction finding by rotating the loop for an audio output null or a tuning meter null. (A 180° ambiguity in direction is possible in the LOOP mode since the loop antenna pattern has two nulls 180° apart.) The direction from which signals are best received can be chosen manually from the control box by positioning the loop. In the ADF mode, the receiver combines signals from both the sense and loop antennas to determine whether the loop is pointed to the left or to the right of the signal source. The receiver commands clockwise rotation of the loop if the loop axis is pointed to the left of the signal source. Counterclockwise rotation is commanded if the loop axis is to the right of the signal source. Rotation ceases when the loop axis is pointed directly at the signal source.



NOTE: WAVE SHAPES DESIGNATED "A" OCCUR WHEN LOOP AXIS IS TO THE RIGHT OF NULL POSITION; "B" OCCUR WHEN LOOP AXIS IS TO THE LEFT OF NULL.

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Figure 2-8.—AN/ARD-13, simplified block diagram.

The position of the loop is continuously transmitted to the bearing indicator. The bearing indicator reads the bearing to the station in the ADF mode, because the loop is kept pointed directly at the station. The bearing indicator combines the bearing information from the direction finder with navigation data received from other equipment. Audio signals in all three modes are supplied to the intercommunication system (ICS) in the aircraft. The audio level to the ICS is varied manually from the control box.

Theory of Operation

Refer to figure 2-8 at frequent intervals throughout the remainder of this discussion.

ANT (ANTENNA) MODE.—Radio frequency signals from the sense antenna are coupled to the RF amplifier through the impedance-matching network in the sense antenna coupler. The only signal input to the RF amplifier in the ANT mode comes from the sense antenna; the loop amplifier and the balanced modulator are disabled. The oscillator and mixer convert the output of the RF amplifier to 455.7 Hz, the intermediate frequency of the receiver. The oscillator is tuned from the control box by the tuning servo. One of two mechanical filters passes the desired signal and attenuates the undesired signals. The broad filter provides selectivity of 3.1 kHz, and the sharp filter provides receiver selectivity of 1.5 kHz. The narrow band output of the mechanical filters is amplified by the IF amplifier and is applied to the detectors. The output of one detector is used as the automatic volume control (AVC) signal to limit the gain of the RF and IF amplifiers. The AVC signal is also applied to the tuning meter. The output of the other detector is applied to the audio amplifier. The audio gain control is bypassed in ANT mode and receiver gain is manually controlled by using the RF gain control. The audio amplifier increases the output of the detector to the level required by the ICS in the aircraft.

LOOP MODE.—Rotation of the loop antenna is controlled by the LOOP switch on the control box. The LOOP switch applies either of two phases of 400-Hz ac from the receiver to the loop rotating motor in the loop antenna. In practice, the operator uses the LOOP switch to drive the loop antenna to the position of minimum reception of the received signal. This position of minimum reception, which occurs when the loop antenna is pointed directly at the signal source, is called the null position. The angle of the transmitting station, with respect to aircraft heading, can then be read accurately on the bearing indicator. The RF output of the loop antenna is applied to the balanced modulator through the loop amplifier. The balanced modulator is unbalanced during loop operation and couples the output of the loop amplifier to the RF amplifier. Signals from the balanced modulator are the only input to the RF amplifier in the loop mode. The input to the RF amplifier is the same as in the antenna mode operation.

ADF MODE.—The RF output of the loop antenna has either of two phases relative to signals from the sense antenna. Phase A, as shown, occurs when the loop antenna is to the right of the null position. Phase B occurs when the loop is to the left of the null. The loop antenna has no output when in the null position. Either output phase of the loop antenna is modulated by a 47-Hz signal in the balanced modulator stage. The results of modulation for either phase input are shown.

The output of the balanced modulator is added to signals from the sense antenna by the RF amplifier. Note that there is a 180° difference in phase between the envelope of A, present when the loop antenna is to the right of the null, and envelope B, present when the loop antenna is to the left of the null. The output of the IF amplifier is amplified and detected, and is applied to the audio amplifier. The output of the audio amplifier is processed and applied to the 47-Hz amplifier.

The amplified 47-Hz component of the output of the audio amplifier is applied to the discriminator. The discriminator compares the phase of the 47-Hz signal from the 47-Hz amplifier with the reference phase from the 47-Hz oscillator. If the two are in phase, the discriminator applies a positive dc level to the 400-Hz modulator. If the two are out of phase, the discriminator applies a negative dc level to the 400-Hz modulator.

The 400-Hz modulator applies either a phase A or phase B 400-Hz signal to the loop servo amplifier, which is connected to one winding of the loop antenna drive motor; phase A if the dc level from the discriminator is positive, and phase B if the input from the discriminator is negative. Phase A causes the loop antenna to rotate to the left, phase B to the right. Thus, the signal that drives the loop antenna motor will always cause the loop antenna to rotate toward the null position.

The bearing indicator, electromechanically coupled to the loop antenna by synchros, reads the position of the loop and thus the direction to the signal source.

In the ADF mode, the RF gain control is inoperative. The audio gain control is used to vary the audio output level of the receiver.

ADF Bearing Limitations

Various factors contribute to inaccuracy in radio bearings. As a maintenance technician you should keep these in mind when analyzing reported ADF discrepancies. Some of the more important of these factors are:

NIGHT EFFECT.—This is caused by the reflection of skywaves from the ionosphere; night effect is most noticeable for about one hour, around sunrise and sunset. At these times, the height of the ionosphere is changing, and the reflected skywaves vary in their intensity and range. This fluctuation interferes with the reception of the groundwave. Since the operation of the ADF depends on the reception of groundwaves, the loop antenna tends to hunt, causing the bearing needle to fluctuate.

ELECTRICAL DISTURBANCE.—Radio waves are distorted by electrical storms, and this results in extremely erratic hunting of the loop antenna and bearing needle, and the antenna tends to home in the direction of the electrical storm.

PRECIPITATION STATIC.—An aircraft may accumulate a static charge when moving through the air, especially air that is laden with particles (dust, ice crystals, etc.). These particles may already have a charge on them, or create one through frictional contact with the aircraft surfaces. These charges tend to discharge from surface to surface or off into the air, and in so doing, intermittently cause interference with the ADF equipment.

QUADRANTAL ERROR.—When incoming radio waves strike an aircraft's surface, a number of reradiated fields are created around the metallic portions of the aircraft. These fields bend the radio waves prior to reception by the loop antenna. Thus, all bearings are in error by the amount of this deflection. This error, known as quadrantal error, is maximum when incoming radio signals must cross the wings or stabilizer surfaces before striking the loop antenna. Quadrantal error is usually compensated for by compensating circuits installed in the loop antenna unit. For this reason, whenever a new loop antenna unit is installed in an aircraft, it must be calibrated in accordance with the maintenance manual for the equipment.

UHF ADF SYSTEM

In Chapter 1 we discussed the AN/ARC-159 UHF transceiver, and mentioned that it provided ADF operation. In actuality a UHF ADF system is comprised of more than one unit. The total typical system is comprised of an ADF antenna, a coaxial relay (to select either normal UHF antenna or the ADF antenna), a control amplifier (to drive the ADF antenna), a UHF transceiver which is wired for ADF, and a bearing indicator. Figure 2-9 is a block diagram of a typical UHF ADF system. Note the receiver in the figure could be an ARC-159, since it is wired for ADF operation. Refer back to figure 1-12; note the OFF/MAIN/BOTH/ADF mode selector switch. Placing the mode selector switch to the ADF position would actuate the coaxial relay shown

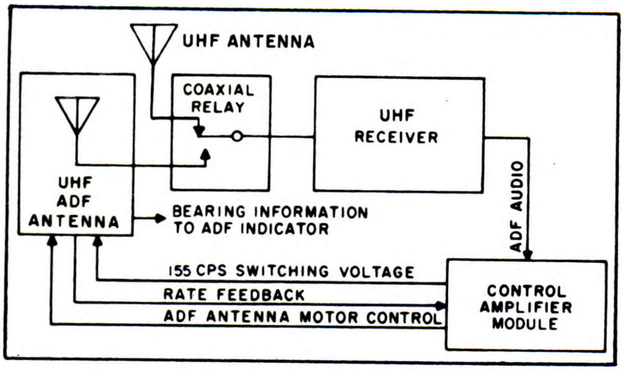

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Figure 2-9.—Typical UHF ADF system block diagram.

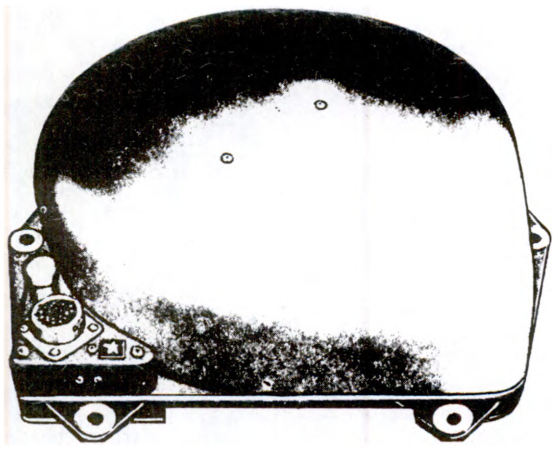

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Figure 2-10.—Antenna AS-909/ARA-48.

in figure 2-9 and provide an audio signal to the control amplifier module. The control amplifier module contains the circuitry to steer the ADF antenna, much the same as the ARD-13 drove its loop antenna.

The heart of a UHF ADF system is the directional antenna. Because of the design of the typical antenna, no sense antenna is required as with the loop antenna. A typical UHF ADF antenna is the AS-909/ARA-48. (See figure 2-10.) It is a flush-mounted type antenna. It receives signals in the 225.0- to 400.0-MHz range. The antenna unit (fig. 2-11) consists of a directional receiving element, an antenna drive motor, a rate generator, a lobing switch, and the associated gear assembly necessary to mechanically link the items. The antenna is a cavity-backed complementary slot radiator that is formed by the position of a rhombic shaped metal plate. The antenna element is terminated alternately at either end by use of the antenna lobing switch G1. This action allows the antenna field, which is a cardioid, to be reversed 180 degrees, 155 times each second, by a signal from the control amplifier module. It is this switching of the field which prevents ambiguous 180 degree readings of the received signal, and eliminates the need for a sense antenna. The switching of the cardioid antenna pattern causes the received RF signal to be square wave modulated. The degree of modulation is proportional to the angle at which the RF signal is received by the antenna element. (Refer to figure 2-12.) The AS909/ARA-48 develops the modulation as follows: in figure 2-12, assume that a signal is received from the direction OX$_1$ (O is the center of fig. 2-12[B]). The resulting modulated input to the control amplifier module (see figure 2-9), after being detected in the UHF receiver, is of the form shown in figure 2-12(C). A motor control voltage proportional to the difference between OA$_1$ and OB$_1$ is then applied from the control amplifier module to the antenna drive motor B1 (fig. 2-11). B1 drives the antenna element toward the null position indicated by OX$_0$ (fig. 2-12[B]). When a signal is received along this null axis, the difference in modulation resulting from the switching of the antenna field pattern is zero. Under these conditions, the motor control voltage applied to B1 is zero, and the antenna ceases to rotate.

Synchro generator B2 (fig. 2-11), transmits antenna position information to the bearing indicator needle.

A rate feedback voltage proportional to the speed of the antenna rotation is developed by the rate generator, G2, and fed to the control amplifier module where it combines with the input from the UHF receiver to prevent over-steering of the antenna and similar problems.

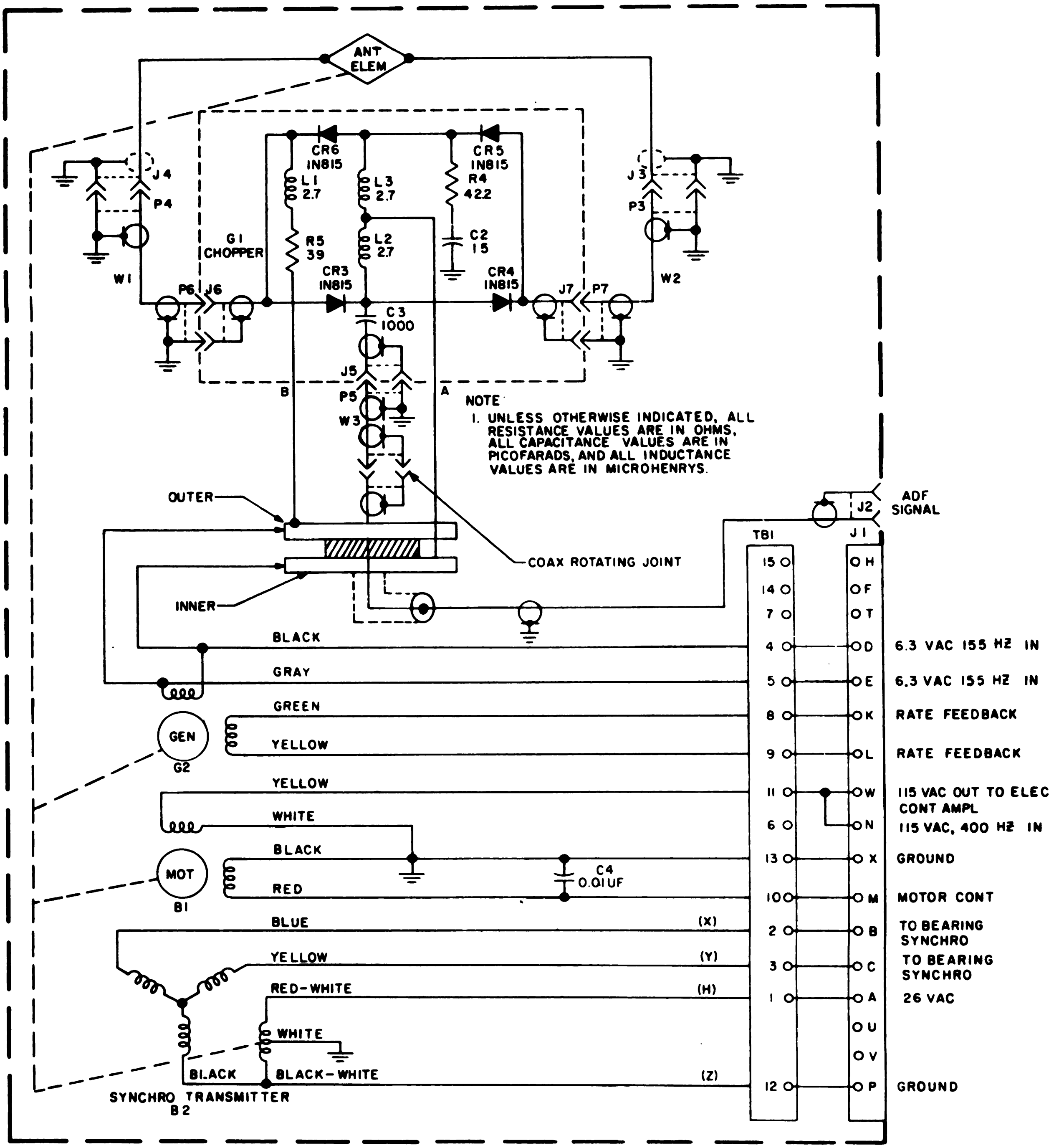

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Figure 2-11.—Antenna AS-909/ARA-48, schematic diagram.

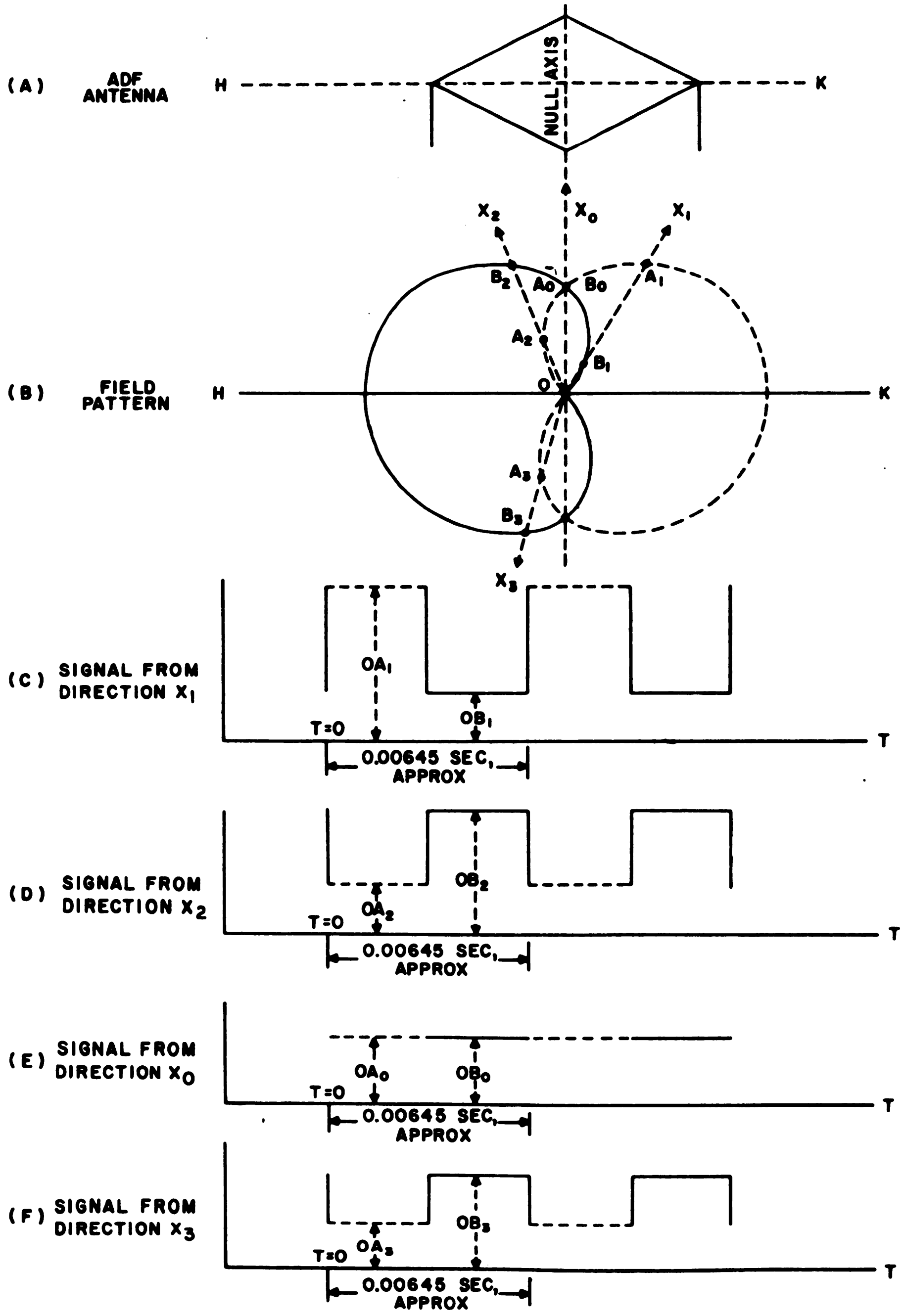

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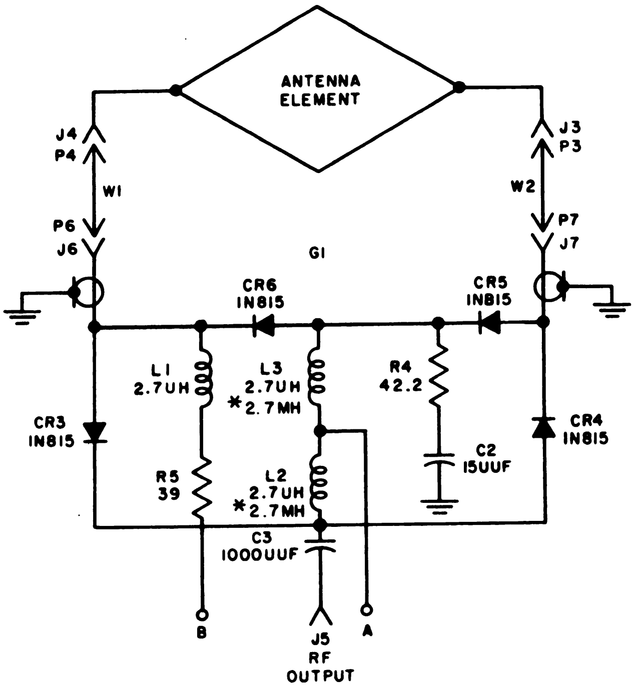
Figure 2-12.—Receiver input levels for various ADF signal paths.



NOTE:
* EFFECTIVE ON CONTRACT NOw60-0540 ONLY

228.200

Figure 2-13.—Electronic lobing switch, simplified schematic diagram.

The electronic lobing switch, G1, (fig. 2-13 and 2-11) uses four diodes to perform the switching function. In the simplified schematic diagram (fig. 2-13), the ADF antenna element is represented as a diamond-shaped plate, the ends of which are connected to J3 and J4 respectively. To examine the operation, assume a 6.3-volt square-wave voltage at 155 Hz incoming from the control amplifier module, and applied between points A and B. A positive voltage at point B places forward bias on CR3 and CR5 (through the antenna element), causing both diodes to conduct and appear as a low value RF impedance. The same potential will bias CR6 and CR4 in the reverse direction, so they are nonconducting. Under these conditions, the J3 end of the antenna element is connected through the resistance of CR5 to the terminating network consisting of R4 and C2. The RF signal is coupled from the J4 end of the antenna element, through CR3 to J5. When the input square wave drives point B negative with respect to point A, CR3 and CR5 are biased off, and CR6 and CR4 are conducting due to the forward bias. The J4 end of the antenna element is then connected to the terminating network R4, C2, while the signal is passed from J3 through CR4 and C3 to J5. Inductors L1, L2, and L3 isolate the RF energy from the 155-Hz control amplifier circuits. Capacitor C2 offers a low impedance to the high-frequency RF signals effectively placing the end of R4 at RF ground, while isolating the 155-Hz circuitry by the relatively high reactance at 155 Hz.

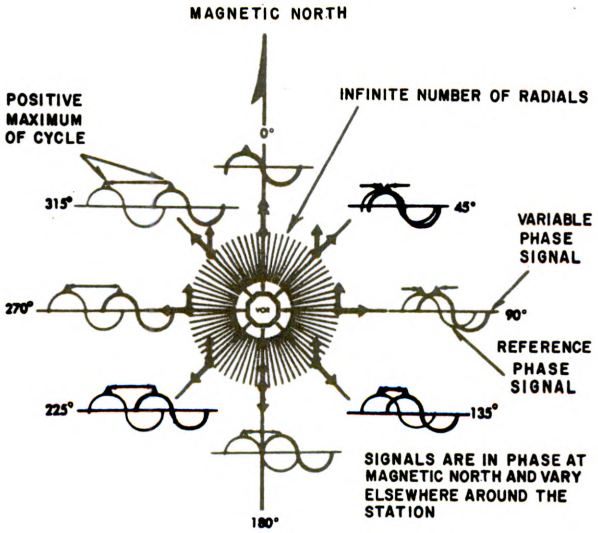
Although the typical UHF ADF antenna is better than the standard LOOP/SENSE antenna, it is still vulnerable to some of the factors which could cause bearing inaccuracies. Operating in the UHF frequency spectrum, the radio signals experience minimal "night effect" errors, but are subject to quadrantal and electrical disturbance errors.

VOR
(VHF OMNIDIRECTIONAL RANGE)

A VOR facility is a radio range station whose transmitting radiation patterns produce directional courses or "tracks" by having special characteristics in its emissions, recognizable as bearing information. These courses or "tracks" remain stationary with respect to the surface of the earth and serve to guide aircraft over long distances.

The operation of a VOR bearing function may be compared to that of an airport beacon light. If the beacon light, rotating at a known speed, blinks each time it sweeps past magnetic north, and the time from that blink until the beam sweeps past an aircraft is measured, the magnetic bearing from the beacon can be determined. For example, if the beam revolves at 1° per second and 120 seconds are counted between the reference blink (magnetic north) and the time the beam strikes the aircraft, the aircraft is on the 120° radial (TRACK) from the beacon.

The transmission principle of the VOR station is based on the creation of a phase difference between two simultaneously transmitted RF signals in the frequency band of 112.0 to 117.9 MHz. Magnetic north is used as the base for measuring the phase relationship.


MAGNETIC NORTH
POSITIVE MAXIMUM OF CYCLE
INFINITE NUMBER OF RADIALS
0°
315°
45°
VARIABLE PHASE SIGNAL
270°
VOR
90°
REFERENCE PHASE SIGNAL
225°
135°
SIGNALS ARE IN PHASE AT MAGNETIC NORTH AND VARY ELSEWHERE AROUND THE STATION
180°

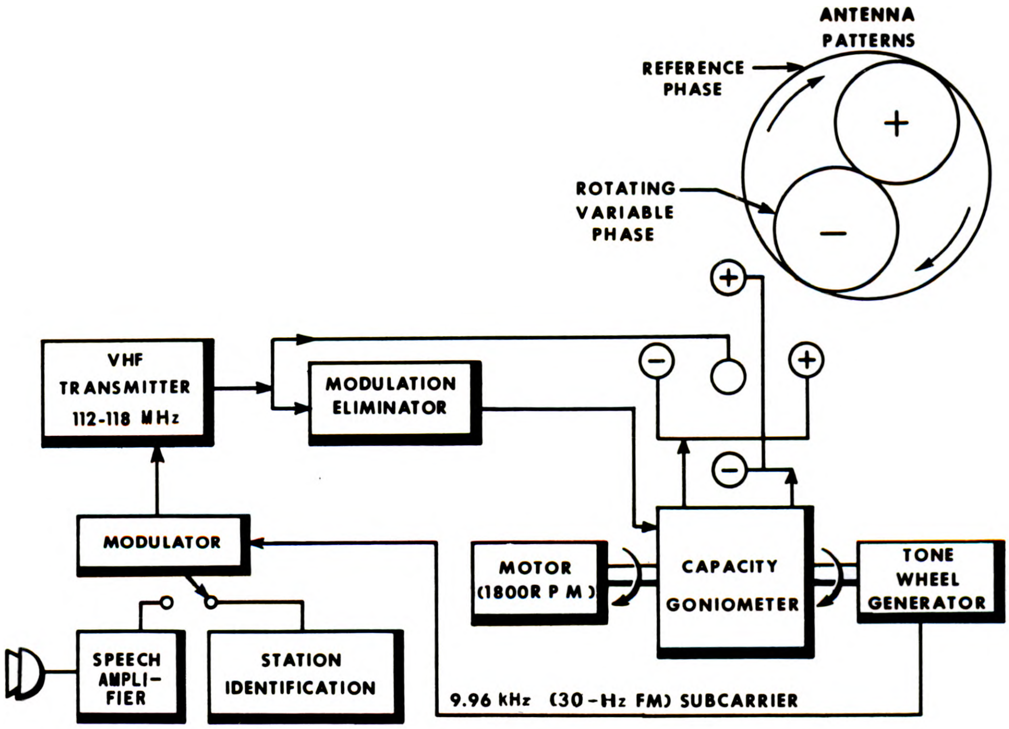
243.134

Figure 2-14.—VOR transmitter.

(See figure 2-14.) One of the two RF signals transmitted is nondirectional and has a constant phase throughout 360 degrees of azimuth. It is called the reference phase signal. This signal is transmitted on a 9.96-kHz subcarrier, frequency modulated at 30 Hz, and is applied to the center loop of a five-element antenna array. (See figure 2-15.)

The second signal is a rotating signal with a speed of 1,800 rpm (30 rps). It is called the variable phase signal.

As shown in figure 2-15, the VOR transmitter is modulated both by a 9.96-kHz subcarrier and by an additional component, either of voice or the station identification code characters. The subcarrier is frequency modulated at 30 Hz and is generated by a notched tone wheel rotating in a magnetic field. The purpose of the subcarrier is to provide a means for separating the 30-Hz tone of the reference phase from the variable tone of the same frequency.

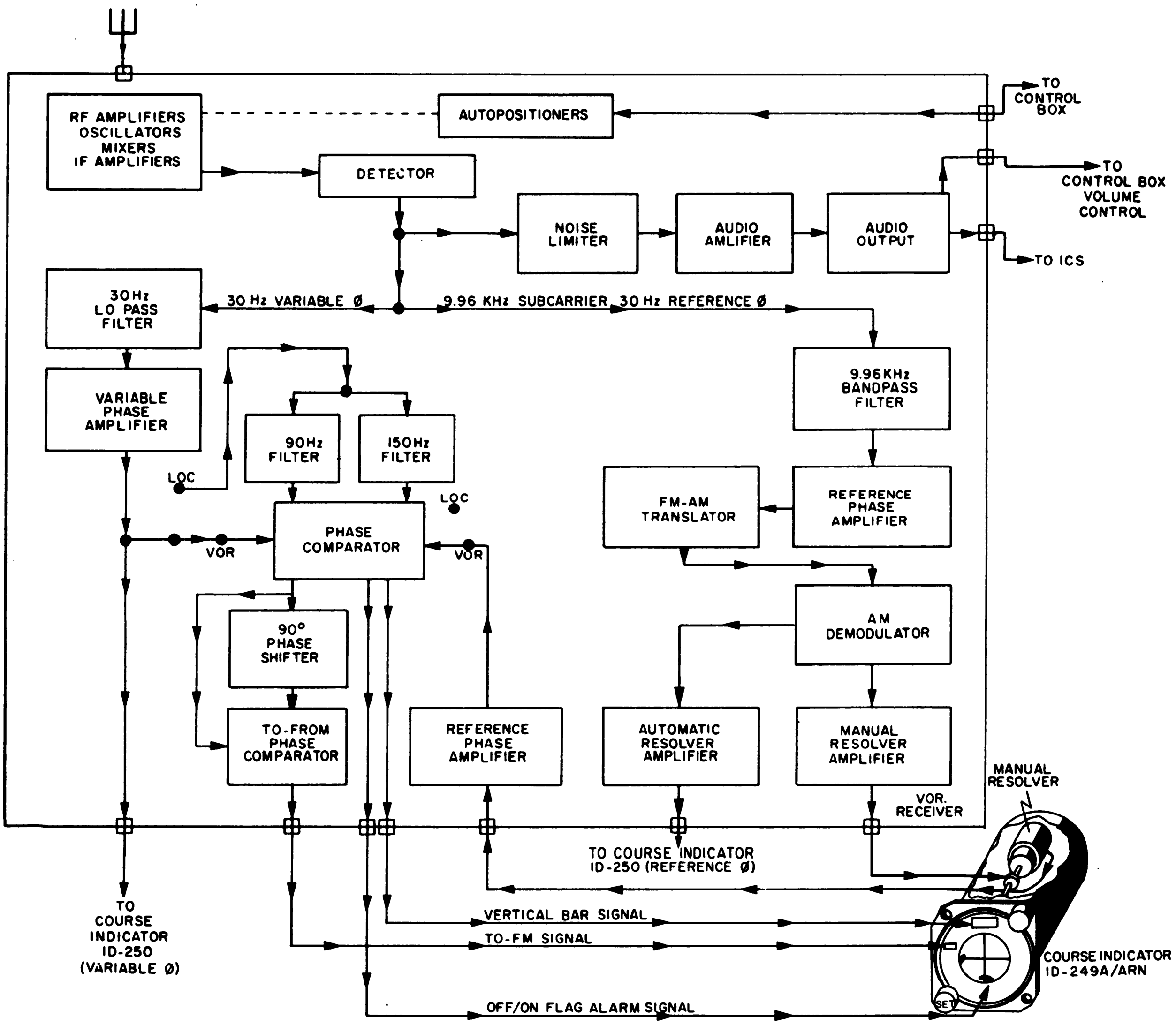


228.90.1

Figure 2-15.—Typical VOR transmitting station.

The modulated output of the transmitter is applied to both a modulation eliminator and to the center loop antenna of a five-element array. There it is radiated to form the reference phase signal. The modulation eliminator is a clipper which removes the amplitude modulation from the carrier. The unmodulated output is fed to a capacity goniometer which serves as a mechanical sideband generator. The goniometer is a motor-driven, double capacitor in which one set of stator plates is displaced 90° from the other set. The rotor plates to which the RF signal is applied are driven at 1,800 rpm (30 rps).

Two outputs are derived, one from each set of stator plates. These two signals contain modulation components (30 Hz) which differ in phase by 90° because of the capacitor plate relationship. One output is fed to one pair of diagonally opposite loop antennas, and the other is fed to the remaining pair of



228.201

Figure 2-16.—Typical airborne VOR receiver simplified block diagram with ID-249.

loops in the square array. Each pair of corner antennas produces a figure-of-eight radiation pattern. These two patterns are displaced from each other by 90° in both space and time phase. The resultant pattern is the sum of the two crossed figure-of-eight patterns and consists of the rotating field. The transmitter is designed so that the 30-Hz frequency modulated component reaches its positive maximum at the same time that the rotating pattern maximum passes magnetic north (in phase). As a result of the rotation of the variable phase pattern, the signal induced in the airborne VOR receiver is amplitude modulated with 30-Hz variations. The receiver develops this tone and compares it with the reference signal. The amount of phase difference between the two signals depends on the location of the aircraft with respect to the transmitting station. (See figure 2-14.) Although the VOR provides an infinite number of courses from the station, for simplicity it is referred to as providing 360 courses 1° apart. These courses are called radials. Any radial may be selected and flown, or may be used to obtain a line of position at any time.

TYPICAL AIRCRAFT VOR SYSTEM

A typical aircraft VOR (omni) system consists of a receiver, control box, course deviation indicator (ID-249 or equivalent), course indicator (ID-250 or equivalent) and an antenna. Figure 2-16 is a simplified block diagram of a typical VOR receiver. Figure 2-17 is a picture of the course deviation indicator and course indicator used by the system, and figure 2-18 is a diagram of a typical VOR control box. (NOTE: refer to these figures during the following discussion.)

VOR Receiver Operation

The VOR control box contains an ON-OFF power switch, which applies power to the complete system, two tuning controls (1 MHz and .1 MHz) to select the receiver's frequency, a frequency indicator, a volume control for adjusting the VOR audio fed to the ICS, and a VOR-LOCALIZER function select switch. The LOCALIZER function will be discussed later in this chapter under Instrument Landing System (ILS).

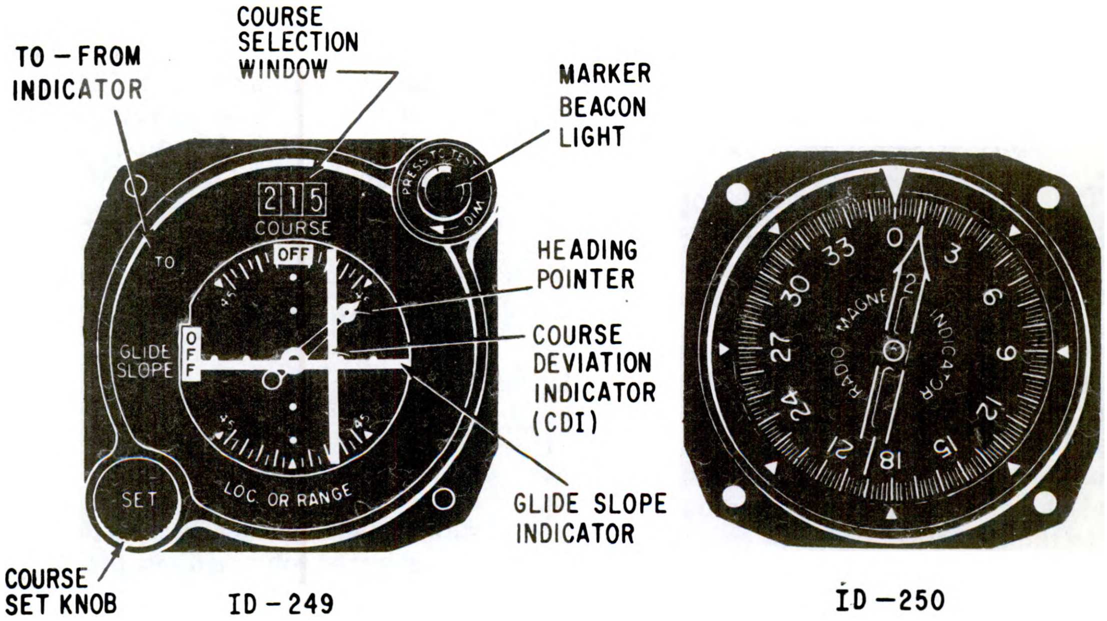


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Figure 2-17.—Typical VOR indicators.

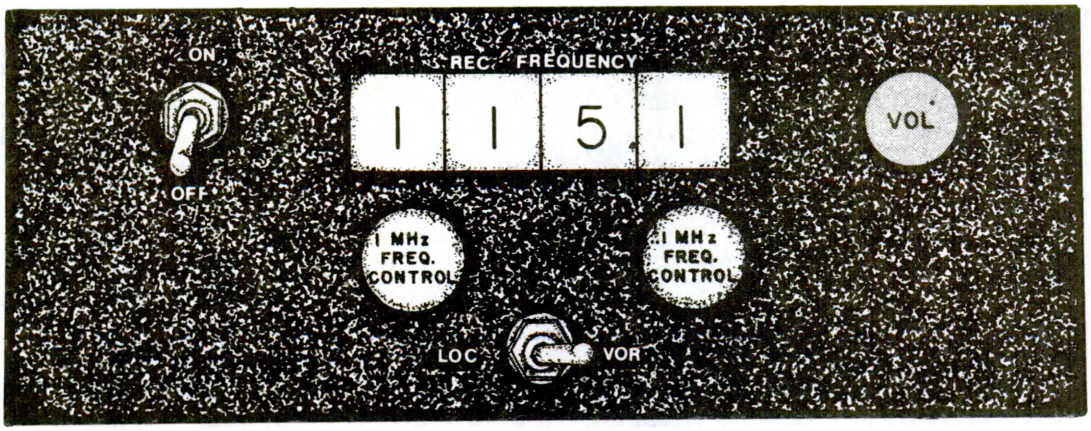

Figure 2-18.—Typical VOR control box.

Table 2-1.—VOR Station Frequency Bands and Their Uses

Frequencies	Use
108.0 - 110.9 mc inclusive	Tone Localizer
111.0 - 111.9 mc	Weather Broadcast
112.0 - 117.9 mc	VHF Omni-Range
118.0 - 121.9 mc	Tower (voice)
122.0 - 135.9 mc	Communication (voice)

The control box tuning controls enable the operator to select any desired VOR station frequency between 108.0 MHz and 135.9 MHz. Table 2-1 is a breakdown of VOR station frequency assignments and their uses.

The control box electrically operates the receiver's autopositioners, which mechanically tune the RF amplifier circuits, local oscillators and mixer stages to the desired frequency.

As in any superhetrodyne receiver, the received signals are processed by the RF amplifiers and converted to a lower IF frequency for demodulation. The portion of the received signal which contains voice or station identification is detected and fed to the audio circuits and out to the aircraft's ICS.

The portion of the received signal which contains omni-bearing information (30-Hz modulated variable phase and 9.96-kHz subcarrier, 30-Hz frequency modulated reference phase) are fed to the instrumentation circuits. The instrumentation section of the receiver is divided into two channels, referred to as the reference phase channel and the variable phase channel. The reference phase channel is concerned with the 9.96-kHz subcarrier, frequency modulated by the 30-Hz reference signal. The subcarrier signal passes through a 9.96-kHz bandpass filter, is amplified and applied to an FM-AM translator. The output of the translator is an AM signal modulated with a 30-Hz component. It also still contains the original FM signal. This signal is fed to an AM demodulator bridge circuit and the resulting 30-Hz output is amplified and applied to a manual resolver located in the course deviation indicator. It is also amplified by an automatic resolver amplifier and is applied to windings of a resolver located in the course indicator (NOTE: This signal will be mixed with a 30-Hz signal from the variable phase channel to drive the pointer to the correct bearing to the station.)

The reference phase signal applied across the course deviation indicator manual resolver, re-enters the receiver, and is again amplified and applied as one input to a phase comparator. The variable phase channel accepts the 30-Hz variable phase signal obtained at the output of the detector, amplifies it, and applies the signal as the second input to the phase comparator. It also applies the signal to the course indicator resolver windings to compare it with the reference phase signal and drive the pointer to the correct bearing to the received station.

The output of the phase comparator is a vector summation voltage (ac) which is applied to three different places. First it is applied to the course deviation indicator flag alarm circuit to drive the ON-OFF flag to indicate adequate station signal reception. It is also applied to resolver windings in the course deviation indicator. The reference phase signal in the course deviation indicator manual resolver is compared with the variable phase signal, and the resulting vector summation voltage will drive the vertical bar either left or right of center, depending on whether the course to the station is left or right of the course set in the ID-249 course selection window. By turning the Course Set Knob, the vertical bar can be centered and the reading in the course selection window should be the same as that bearing indicated by the pointer of the ID-250. Another use of the course deviation indicator is to select a desired course to the station and fly the aircraft in a direction so as to center the vertical bar, thus ensuring that the aircraft would be on the desired course. This is illustrated in figure 2-19.

The third output of the phase comparator is fed to a TO-FROM phase comparator and a 90° phase shifter circuit, and to the TO-FROM phase comparator. The vector summation voltage output of the TO-FROM phase comparator is applied to the ID-249 TO-FROM to drive the TO-FROM indicator flag. If a received signal is "from" the course selected in the course selection window, the TO-FROM flag will read "FROM." If the course set is to the station, the TO-FROM flag will read "TO." As illustrated in figure 2-19, the combination of the ID-249 vertical cross-bar position, the course selected in the course selection window, and the TO-FROM indication, will inform the operator just where the aircraft is located with respect to the received VOR station.

INSTRUMENT LANDING SYSTEM

The instrument landing system (ILS), one of the facilities of the federal airways, operates in the VHF portion of the spectrum. The entire system consists of a runway localizer, a glide-path signal, and marker beacons for position location.

The localizer equipment produces a radio course aligned with the center of an airport runway. The on-course signal results from equal reception of two signals—one containing 90-Hz modulation, and the other containing 150-Hz modulation. On one side of the runway centerline, the aircraft receiver develops an output in which the 150-Hz signal predominates. This area is referred to as the blue sector. On the other side of the centerline, the 90-Hz output is greater. This area is referred to as the yellow sector. Most aircraft VOR receivers have localizer circuits built into them to receive and display the 90-Hz and 150-Hz localizer signals on the same ID-249 course deviation indicator used by the VOR system. (Refer to figure 2-18.) There is a VOR-LOCALIZER function switch located on the VOR control box. Placing this switch in the localizer (LOC) position energizes various relays. These allow the 90-Hz and 150-Hz signals to bypass the 30-Hz lo-pass filter of the 30-Hz variable phase channel. (See figure 2-16.) They are then processed the same as the 30-Hz VOR signal with the exception that the localizer signals out of the variable phase amplifier go through 90-Hz and 150-Hz filters respectively and are fed to the phase comparator. At the same time the reference phase channel is disengaged from the comparator. The output of the phase comparator is the vector sum of the 90-Hz and 150-Hz localizer signals vice the variable and reference phase sum described in the VOR section. The operation of the ID-249 vertical bar is solely driven by the output of the phase comparator. Deviation of the aircraft to either side of the runway centerline during final landing approach results in ID-249 indications as shown in figure 2-20.

The localizer transmitter operates at about 110 MHz. The transmissions are made from an antenna array containing eight loops situated about 1,500 feet from the end of the runway. Three kinds of transmissions are made. Six of the loops radiate sideband energy only. Sidebands containing 90-hertz modulation, and those bands containing 150-hertz modulation are separated by a sharp null directed along the centerline of the runway. Two of the loops

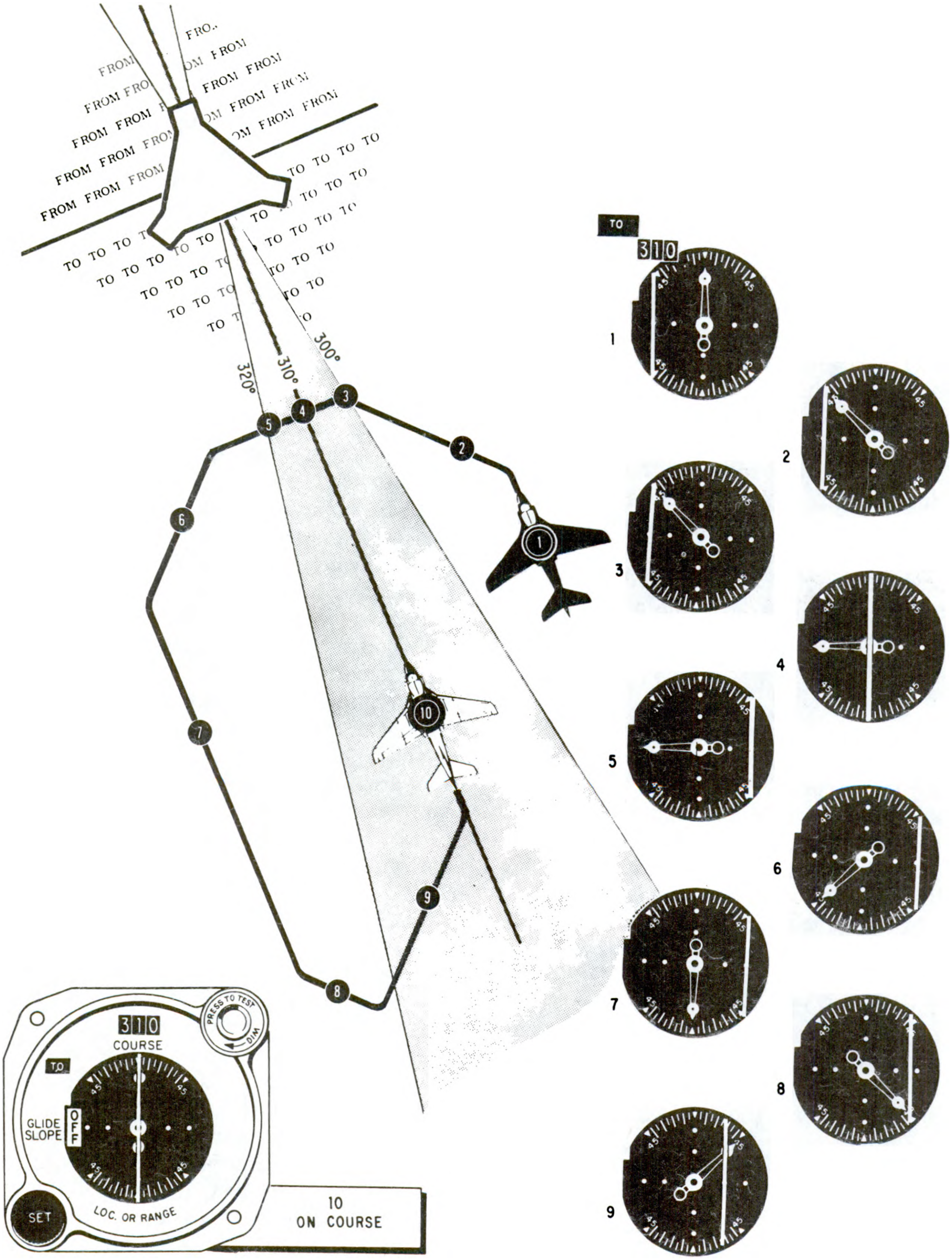

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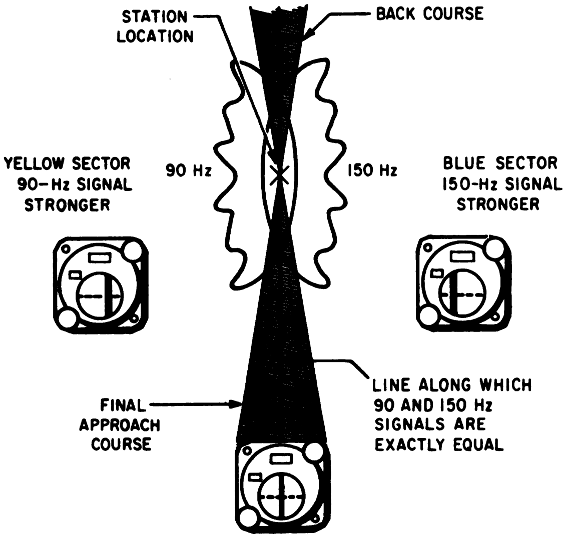
Figure 2-19.—ID-249 presentations at various positions in relation to the VOR station.


STATION LOCATION
BACK COURSE
YELLOW SECTOR 90-Hz SIGNAL STRONGER
90 Hz
150 Hz
BLUE SECTOR 150-Hz SIGNAL STRONGER
FINAL APPROACH COURSE
LINE ALONG WHICH 90 AND 150 Hz SIGNALS ARE EXACTLY EQUAL

228.91

Figure 2-20.—Tone localizer pattern and instrument indications.

radiate the carrier wave containing equal amounts of 90-hertz and 150-hertz tones, and this signal is sent along the null separating the sectors. Signals are received in any location; but as indicated in the figure, only along the runway centerline are the 90-hertz and 150-hertz tones received in exactly equal amounts.

The glidepath is a radio beam which gives vertical guidance, assisting the pilot in making the correct angle of descent to the runway. Glidepath signals are radiated from two antennas which are driven by a crystal-controlled transmitter operating at about 330 MHz. The power output is about 25 watts.

One antenna radiates a beam which is very broad in the vertical plane. This beam contains signals modulated by a 90-hertz tone. The other antenna emits signals modulated at 150 hertz in many lobes which are very narrow in the vertical plane. The undesired lobes are too high (fig. 2-21) to be encountered in a normal approach. The glidepath is an area of intersection between the broad 90-hertz lobe and the lowest of the 150-hertz lobes. In this area, which is a conical beam, the receiver develops equal amounts of 90-hertz and 150-hertz signals in the output.

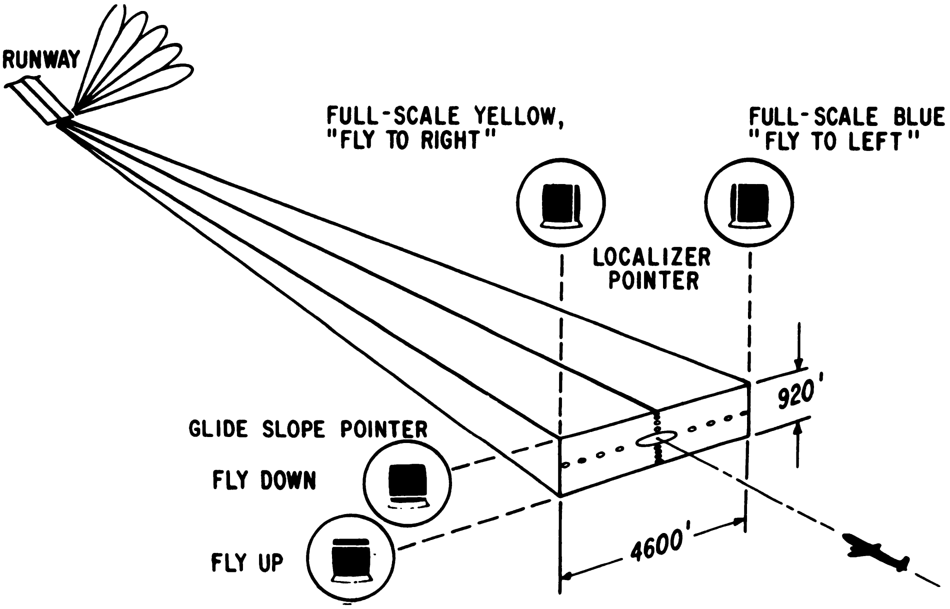


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Figure 2-21.—Cross section of ILS course.

The beam is inclined about 2.5° from the horizontal.

The glidepath receiver is a crystal-controlled superheterodyne receiver which is powered entirely from a 28-volt dc source and requires no high voltage power. The receiver audio output containing the 90-hertz and 150-hertz tones is filtered, and the two signals are rectified separately. The resulting direct current is applied to a zero-center microammeter which indicates by means of a horizontal pointer. (The localizer and glidepath indicators are actually mounted on the same instrument. However, in most military installations the glidepath equipment is not employed.) The pilot flies the glidepath by keeping the horizontal pointer in the center of the dial.

Figure 2-21 shows how the glidepath would appear. The cross section is shown from the runway to a distance of 10 miles. At that range the glidepath appears to be 920 feet thick (vertically) and 4,600 feet wide. By keeping both pointers centered, the pilot may fly to the runway without seeing the ground. However, once over the runway, the pilot must be able to see the runway in order to land.

ILS MARKER BEACONS

ILS marker beacons transmit on the assigned frequency of 75 MHz. The function of marker beacons is to identify a particular location in space along an airway or on the approach to an instrument runway. The ILS marker beacons are a part of the instrument landing system and are referred to as the outer marker, the middle marker, and the inner marker. These markers are located on the extension of the instrument runway centerline and are used to mark definite positions along the instrument approach course. The outer marker beacon usually marks the intersection of the approach altitude with the glidepath. It is modulated at 400 hertz and keyed at two dashes per second. The middle marker indicates a point approximately 3,500 feet from the approach end of the runway. It is modulated at 1300 hertz and keyed with alternate dots and dashes. The dashes are keyed at the rate of 2 per second and the dots at 6 per second. The inner marker, sometimes installed at military airports, marks the beginning of the usable landing area on the airport. It is modulated at 3000 hertz and keyed at 6 dots per second.

ILS marker beacons are crystal-controlled transmitters with an output power of approximately 3 watts. The directional antenna array and counterpoise are designed to produce an elliptical pattern which is directed straight upward.

Typical Airborne Marker Beacon Receiver

The typical airborne marker beacon receiver is a 75-MHz, crystal-controlled, superheterodyne receiver, designed with a very high selectivity in order to suppress adjacent frequencies. This ensures that undesirable signals will not interfere and cause a false marker beacon indication. The reception of a marker beacon signal is indicated by means of a light, similar to the one mounted on the ID-249. (See figure 2-17.) In addition an aural tone is heard via the ICS.

Figure 2-22 is a simplified block diagram of a typical marker beacon receiver. The antenna is usually flush mounted under the forward part of the aircraft fuselage.

The signal input from the antenna, as it passes over the transmitter's antenna pattern, is applied to a 75-MHz filter, which increases the receiver selectivity and also prevents radiation from the receiver's local oscillator into the antenna. The 75-MHz signal is heterodyned in the mixer, usually with a local oscillator frequency of around 68 MHz, to form an IF frequency of about 7,000 kHz. This high IF frequency increases the image frequency rejection of the receiver.

The output of the mixer is then amplified by the 1st IF amplifier. This amplifier normally employs input and output adjustments to calibrate the receiver's minimum and maximum sensitivity. The signal is again amplified in the 2nd IF amplifier, which incorporates a varistor (voltage sensitive resistor) in its emitter circuit to compensate for variations in the supply voltage. (This may occur from varying engine rpm during the landing approach.) The signal is then demodulated by the detector. The audio frequency out of the detector is then amplified and fed to an audio output stage, to the aircraft's ICS system. It is also fed to an audio rectifier circuit which

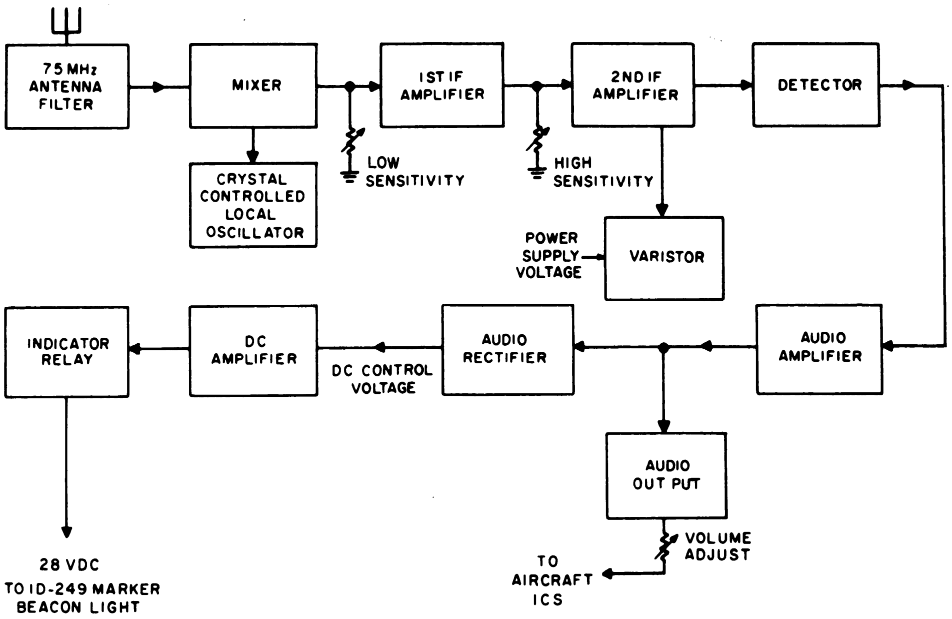

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Figure 2-22.—Typical airborne marker beacon receiver simplified block diagram.

converts the audio signal to a filtered dc control voltage. This dc voltage (representing the received marker beacon signal) is then amplified by a dc amplifier, the output of which operates an indicator relay. The relay applies 28 V dc out of the receiver, to the marker beacon indicator lamp, each time it is energized by the incoming signal. The lamp will light (flash) at the same rate as the modulating frequency of the received signal from the marker beacon transmitter. In this manner a pilot can judge the aircraft's position in relation to the runway during an ILS approach.

TACAN (TACTICAL AIR NAVIGATION)

The tactical air navigation (TACAN) system is a short-range navigation system which supplies continuous, accurate, slant-range distance and bearing information. Much like VOR, TACAN transmitting stations provide an infinite number of courses (radials) to or from the station. Further, through distance measuring equipment (DME), which is an integral part of TACAN, slant-range distance information from the station is furnished continuously. Therefore, TACAN is more useful than VOR, because not only does a pilot know the aircraft's bearing from a particular ground station, but also its exact mileage. In this way, the aircraft's exact position is known from a single received station signal. The TACAN ground facility consists of a receiver-transmitter combination (transponder) and a rotating type of antenna for transmission of bearing and distance information. The TACAN facilities (stations) are commonly referred to as beacons. The beacon (station) identifies itself every 37.5 seconds by transmitting an International Morse code three-character signal. A pilot has an approach chart manual which identifies a particular beacon by the three-character letters.

The maximum range for reception of TACAN signals is limited to line-of-sight, as TACAN operates in the UHF (1000 MHz) band. It is also limited for DME by power output of the ground station and the aircraft's transceiver. A typical airborne TACAN navigation set is capable of receiving DME (range) and bearing information up to 300 nautical miles. However, due to line-of-sight restrictions on UHF transmissions, the aircraft would have to be at an altitude of around 75,000 feet to receive the signals at the maximum range.

TACAN STATION SIGNAL PATTERNS

The signal pattern for bearing information is formed by varying the nondirectional pattern sent from the stationary central element of the antenna. This is accomplished by a plastic cylinder in which is embedded a vertical metal wire parasitic element. This cylinder (fig. 2-23) rotates around the central element of the antenna at 15 rps. The wire embedded in the cylinder distorts the radiated signal into a cardioid pattern and its rotation causes the cardioid pattern also to revolve at 15 rps. This resulting rotating pattern is referred to as the COARSE pattern. From this, the aircraft TACAN receives a 15-Hz amplitude modulation. This means that the strength of the signal goes from maximum to minimum at the rate of 15 Hz.

Around the central element and the smaller cylinder is mounted another cylinder, which also rotates at 15 rps, but is larger and has nine wires. This is the FINE antenna which superimposes nine additional lobes onto the already formed coarse pattern, and forms a 135-Hz amplitude modulated signal.

In order to determine the aircraft's position in bearing from the beacon, a phase angle measurement must be made. To measure a phase angle, a fixed reference must be established. This fixed reference is a 15-Hz nondirectional pulse signal normally referred to as the main reference bearing pulse. Note in figure 2-24 that one main reference pulse occurs with each revolution of the antenna. In addition to the main reference pulse, eight auxiliary reference pulses also occur during one revolution of the ground beacon antenna. Therefore, a reference

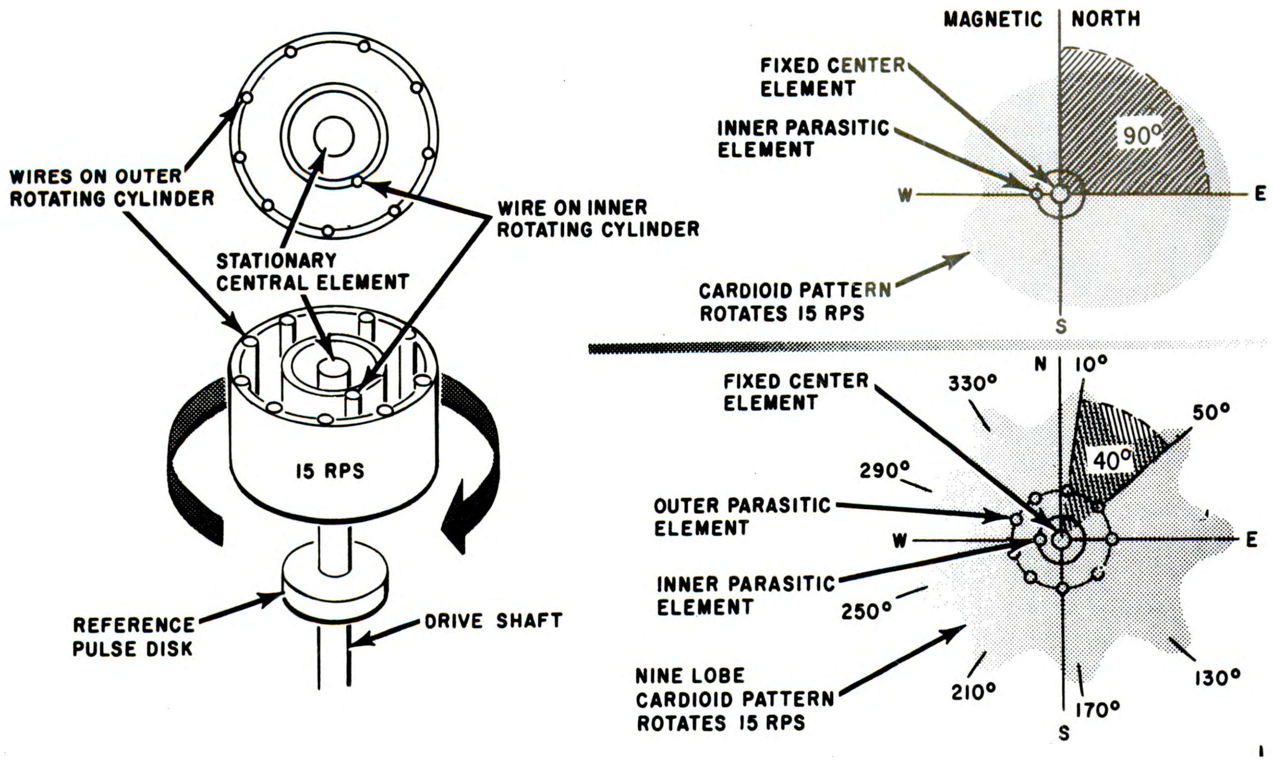

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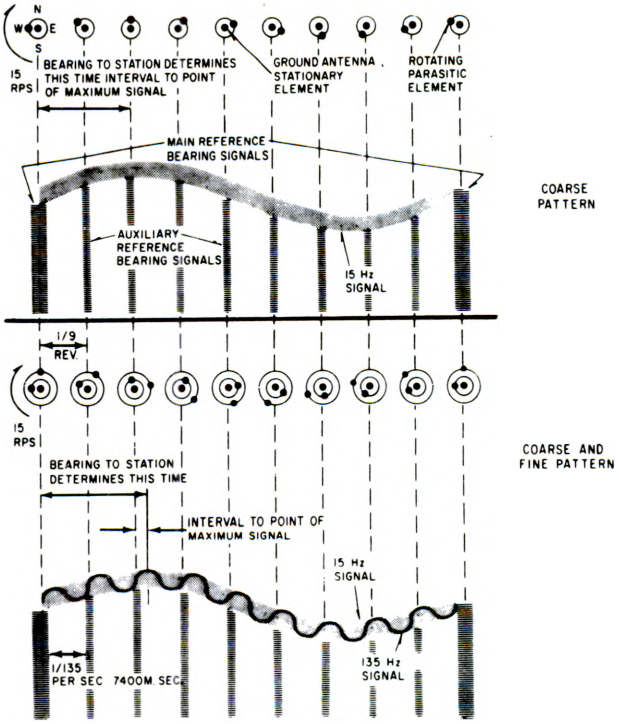
Figure 2-23.—TACAN beacon antenna design and radiation pattern.


N
W
E
S
15 RPS
BEARING TO STATION DETERMINES THIS TIME INTERVAL TO POINT OF MAXIMUM SIGNAL
GROUND ANTENNA, STATIONARY ELEMENT
ROTATING PARASITIC ELEMENT
MAIN REFERENCE BEARING SIGNALS
COARSE PATTERN
AUXILIARY REFERENCE BEARING SIGNALS
15 Hz SIGNAL
1/9 REV.
15 RPS
COARSE AND FINE PATTERN
BEARING TO STATION DETERMINES THIS TIME
INTERVAL TO POINT OF MAXIMUM SIGNAL
15 Hz SIGNAL
1/135 PER SEC 7400M. SEC.
135 Hz SIGNAL

243.150

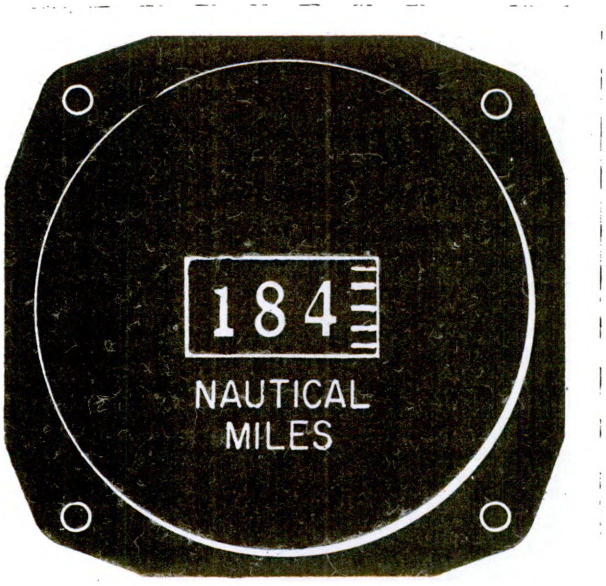
Figure 2-24.—Combined COARSE and FINE bearing signals.

pulse occurs each 40° of antenna rotation. This is shown in the lower portion of figure 2-24.

The airborne TACAN equipment measures the time lapse between the main reference pulse and the maximum amplitude (signal strength) of the 15-Hz rotating signal pattern. This determines the aircraft's bearing from the station within a 40° sector (fig. 2-24). Then the time lapse between the auxiliary reference pulses and the maximum amplitude of the 135-Hz signal is measured to determine the aircraft's position within the 40° sector. The accuracy of this measurement determines the aircraft's position relative to the station within ±1°.

Distance Measuring Equipment

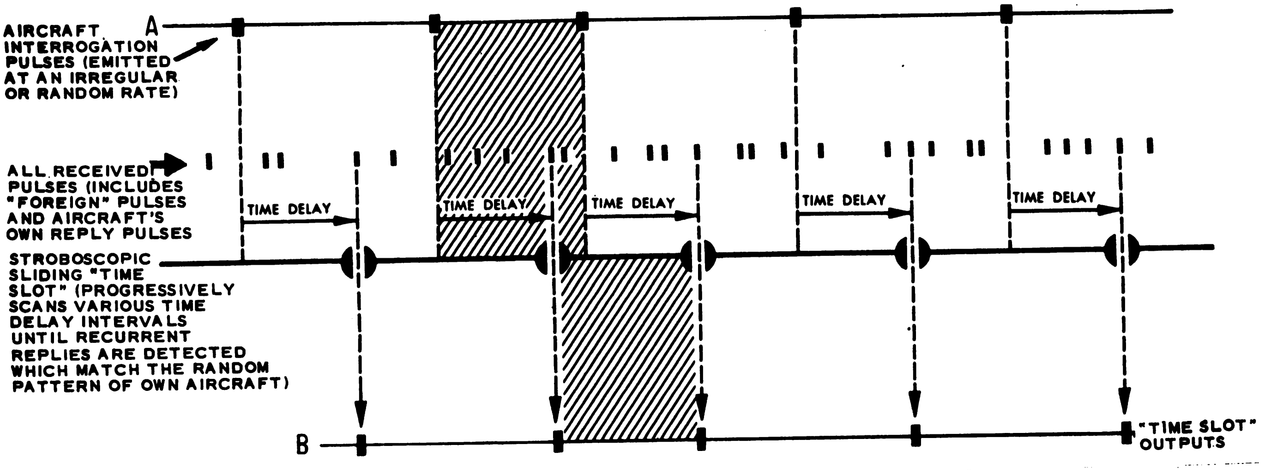
Distance is determined with TACAN equipment by measurement of the elapsed time between transmission of interrogating pulses of the airborne set, and reception of corresponding reply pulses from the ground beacon. The transmitter in the aircraft transceiver starts the interrogation process by sending out the distance interrogation pulse-signals at a low prf. These signals are detected by the receiver of the ground beacon. The ground beacon then triggers its transmitter, automatically sending out the distance reply pulse-signals. These pulses require 12.36 microseconds round trip travel time per nautical mile of distance from the ground beacon. A cockpit instrument, such as the Range Indicator ID-310 (fig. 2-25), displays distance to the TACAN beacon in nautical miles.



243.151

Figure 2-25.—Range Indicator ID-310 (DME).

Since a large number of aircraft could be interrogating the same beacon, the airborne set must be able to sort out for measurement only the pulses which are replies to its own interrogations. Interrogation pulses are generated on an irregular, random basis by the airborne set. (See figure 2-26.) With stroboscopic (search) action, the airborne equipment sorts out only those replies which are synchronized to its own interrogations. (Notice that the pulses in line A of figure 2-26 exactly match the detected time slot outputs (line B) which have been shifted by the time delays.) This searching process occurs automatically whenever the airborne set is turned to a new beacon or when there is a major


AIRCRAFT INTERROGATION PULSES (EMITTED AT AN IRREGULAR OR RANDOM RATE)
A
ALL RECEIVED PULSES (INCLUDES "FOREIGN" PULSES AND AIRCRAFT'S OWN REPLY PULSES
TIME DELAY
STROBOSCOPIC SLIDING "TIME SLOT" (PROGRESSIVELY SCANS VARIOUS TIME DELAY INTERVALS UNTIL RECURRENT REPLIES ARE DETECTED WHICH MATCH THE RANDOM PATTERN OF OWN AIRCRAFT)
B
"TIME SLOT" OUTPUTS

243.152

Figure 2-26.—Detection of correct DME reply pulses.

interruption in beacon signals, and may require up to 20 seconds to complete. This will depend upon the aircraft's actual distance from the beacon at the time.

A memory circuit maintains the same distance indication on the range indicator and prevents the search operation from recurring if the signal is interrupted for less than 10 seconds. This 10-second interruption occurs each time the station identifies itself. After the search operation is completed, the strobe locks on the correct reply pulses and transfers back to track operation. When tracking, the strobe automatically follows any delay variations which it is programmed to accept as normal, such as a variation resulting from the normal flightpath of the aircraft changing the distance to the beacon. Such variations are necessarily very slow because of the relation between the speed of microwave energy and the relatively slow aircraft speeds.

Bearing and distance information is subject to line-of-sight restrictions and, as previously mentioned, is capable of reception up to 300-350 NM. Practical application, however, limits TACAN to a maximum range of about 199 NM in most cases. At lower altitudes, the distance at which a station can be received is reduced even more, thus altitude of the aircraft is a factor to be considered in TACAN operation.

Accuracy of the DME is on the order of plus or minus 600 feet, plus two-tenths percent of the distance being measured. Thus, at a distance of 10 nautical miles from the facility, the maximum distance error is plus or minus 720 feet. Distances are measured slant-range, but for practical purposes, they may be regarded as horizontal distances except when the aircraft are very close to the station.

TYPICAL AIRBORNE TACAN SYSTEM

A typical airborne TACAN system consists of a receiver-transmitter (transceiver), control box, course deviation indicator (ID-249 or equivalent), course indicator (ID-250 or equivalent), range indicator (DME) (ID-310 or equivalent), and two antennas (mounted on the top and bottom of the aircraft's fuselage). The purpose of two antennas, vice one, is to eliminate the possibility of "blind" spots that could interrupt signal reception. Most aircraft employ an automatic switching device, which alternates the connection of the upper and lower antennas to the transceiver. In those aircraft without automatic devices, a manually operated antenna selector switch is available. TACAN ground stations operate in the frequency band of 962 MHz to 1213 MHz. The airborne transceiver has 126 preset channels to receive these signals and to transmit DME (range) interrogation signals. Table 2-2 lists the TACAN transceiver

Table 2-2.—Airborne TACAN System Preset Frequencies

Channel Number	Normal Airborne TACAN Frequencies		Air-To-Air TACAN Frequencies	
	Transmit MHz	Receive MHz	Transmit MHz	Receive MHz
1	1025	962	1025	1088
2	1026	963	1026	1089
3	1027	964	1027	1090
4	1028	965	1028	1091
5	1029	966	1029	1092
6	1030	967	1030	1093
7	1031	968	1031	1094
8	1032	969	1032	1095
9	1033	970	1033	1096
10	1034	971	1034	1097
11	1035	972	1035	1098
12	1036	973	1036	1099
13	1037	974	1037	1100
14	1038	975	1038	1101
15	1039	976	1039	1102
16	1040	977	1040	1103
17	1041	978	1041	1104
18	1042	979	1042	1105
19	1043	980	1043	1106
20	1044	981	1044	1107
21	1045	982	1045	1108
22	1046	983	1046	1109
23	1047	984	1047	1110
24	1048	985	1048	1111
25	1049	986	1049	1112
26	1050	987	1050	1113
27	1051	988	1051	1114
28	1052	989	1052	1115
29	1053	990	1053	1116
30	1054	991	1054	1117
31	1055	992	1055	1118
32	1056	993	1056	1119
33	1057	994	1057	1120
34	1058	995	1058	1121
35	1059	996	1059	1122
36	1060	997	1060	1123
37	1061	998	1061	1124
38	1062	999	1062	1125
39	1063	1000	1063	1126
40	1064	1001	1064	1127
41	1065	1002	1065	1128
42	1066	1003	1066	1129
43	1067	1004	1067	1130
44	1068	1005	1068	1131
45	1069	1006	1069	1132
46	1070	1007	1070	1133
47	1071	1008	1071	1134
48	1072	1009	1072	1135
49	1073	1010	1073	1136
50	1074	1011	1074	1137
51	1075	1012	1075	1138
52	1076	1013	1076	1139
53	1077	1014	1077	1140
54	1078	1015	1078	1141

Table 2-2.—Airborne TACAN System Preset Frequencies—Continued

Channel Number	Normal Airborne TACAN Frequencies		Air-To-Air TACAN Frequencies	
	Transmit MHz	Receive MHz	Transmit MHz	Receive MHz
55	1079	1016	1079	1142
56	1080	1017	1080	1143
57	1081	1018	1081	1144
58	1082	1019	1082	1145
59	1083	1020	1083	1146
60	1084	1021	1084	1147
61	1085	1022	1085	1148
62	1086	1023	1086	1149
63	1087	1024	1087	1150
64	1088	1151	1088	1025
65	1089	1152	1089	1026
66	1090	1153	1090	1027
67	1091	1154	1091	1028
68	1092	1155	1092	1029
69	1093	1156	1093	1030
70	1094	1157	1094	1031
71	1095	1158	1095	1032
72	1096	1159	1096	1033
73	1097	1160	1097	1034
74	1098	1161	1098	1035
75	1099	1162	1099	1036
76	1100	1163	1100	1037
77	1101	1164	1101	1038
78	1102	1165	1102	1039
79	1103	1166	1103	1040
80	1104	1167	1104	1041
81	1105	1168	1105	1042
82	1106	1169	1106	1043
83	1107	1170	1107	1044
84	1108	1171	1108	1045
85	1109	1172	1109	1046
86	1110	1173	1110	1047
87	1111	1174	1111	1048
88	1112	1175	1112	1049
89	1113	1176	1113	1050
90	1114	1177	1114	1051
91	1115	1178	1115	1052
92	1116	1179	1116	1053
93	1117	1180	1117	1054
94	1118	1181	1118	1055
95	1119	1182	1119	1056
96	1120	1183	1120	1057
97	1121	1184	1121	1058
98	1122	1185	1122	1059
99	1123	1186	1123	1060
100	1124	1187	1124	1061
101	1125	1188	1125	1062
102	1126	1189	1126	1063
103	1127	1190	1127	1064
104	1128	1191	1128	1065
105	1129	1192	1129	1066
106	1130	1193	1130	1067
107	1131	1194	1131	1068
108	1132	1195	1132	1069

Table 2-2.—Airborne TACAN System Preset Frequencies—Continued

Channel Number	Normal Airborne TACAN Frequencies		Air-To-Air TACAN Frequencies	
	Transmit MHz	Receive MHz	Transmit MHz	Receive MHz
109	1133	1196	1133	1070
110	1134	1197	1134	1071
111	1135	1198	1135	1072
112	1136	1199	1136	1073
113	1137	1200	1137	1074
114	1138	1201	1138	1075
115	1139	1202	1139	1076
116	1140	1203	1140	1077
117	1141	1204	1141	1078
118	1142	1205	1142	1079
119	1143	1206	1143	1080
120	1144	1207	1144	1081
121	1145	1208	1145	1082
122	1146	1209	1146	1083
123	1147	1210	1147	1084
124	1148	1211	1148	1085
125	1149	1212	1149	1086
126	1150	1213	1150	1087

channels and their respective frequency coverage. You will note that the receiver and transmitter frequencies are 63 MHz apart. In normal reception the transmitter frequency is higher for channels 1 through 63 and lower for channels 64 through 126. For air-to-air operation (A/A) this situation is reversed. Thus any TACAN operating in the normal mode will not respond to A/A transmissions, regardless of the channel selected. Also note that two aircraft operating A/A with each other must be 63 channels apart on their respective TACAN sets in order to marry their respective transmitters and receivers. (See figure 2-27.) Figure 2-28 is a picture of a typical airborne TACAN control box with explanations of its controls.

System Operation

Typical airborne TACAN sets operate with signals from a fixed ground beacon station to provide an indication of the bearing and the distance from the aircraft to the ground station. Bearing information is obtained by a phase comparison between an amplitude-modulated signal and a fixed reference signal. Distance information is obtained by measuring the time delay between a transmitted interrogation signal and a received reply signal from the ground beacon station. The TACAN can also utilize signals from similar equipment in a cooperating aircraft to provide an indication of the distance between the two aircraft.

The signal received by the TACAN set when operating in conjunction with a ground station in the receive-transmit mode, is comprised of a series of double pulses with a 12-microsecond interval between the pulses of each pulse pair. The series of pulse pairs contains five different functional groups; namely, identification tone signals, bearing reference groups, distance reply pulse pairs, random reply pulses, and filter pulses.

Identification tone signals are transmitted every 37.5 seconds to provide an audio signal in International Morse code to identify the ground station. These signals consist of a series of pulse groups at a prf of 1350 Hz with a duration of 0.125 second for a dot and 0.375 second for a dash. Each pulse group consists of two pulse pairs spaced 100 microseconds apart. Two pulse pairs are used in each group to provide an average prf of 2700 pulse pairs-per-second.

Bearing reference groups are transmitted by the ground station to provide phase references for the bearing information signals. Two types

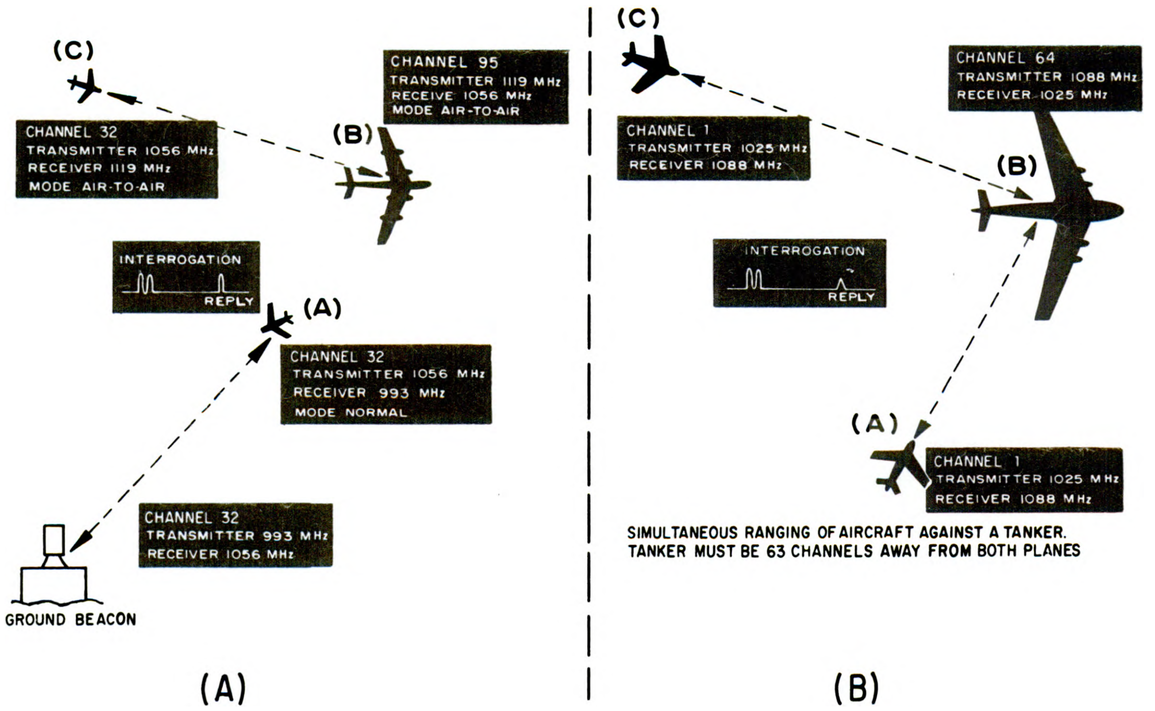


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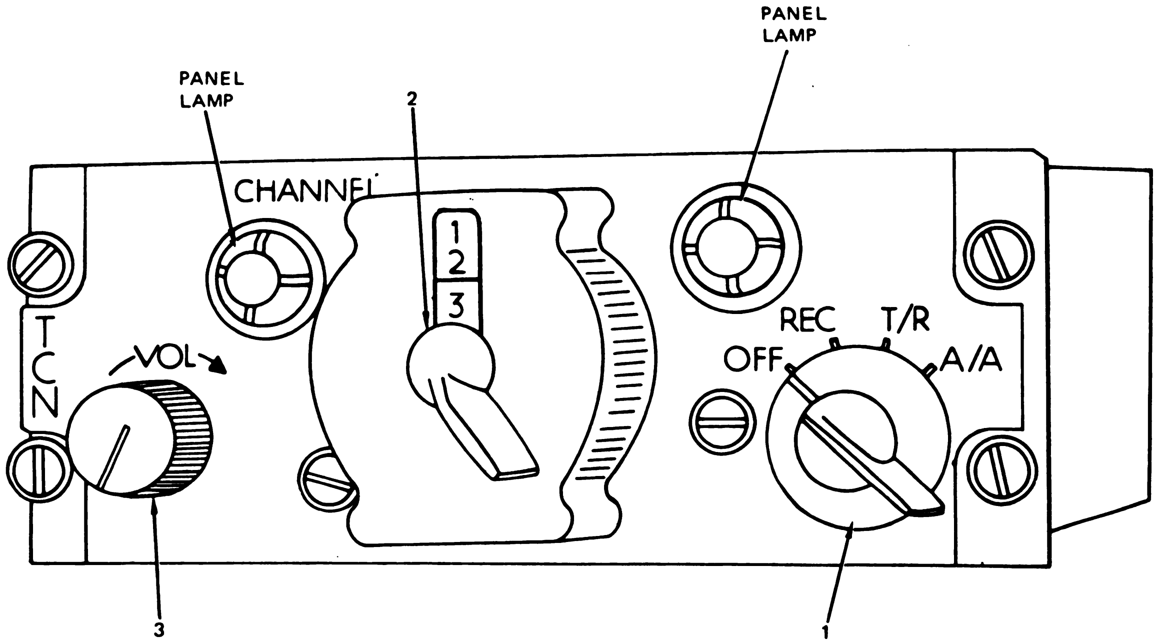
Figure 2-27.—TACAN air-to-air system operation.

of reference groups are provided. Coarse bearing reference groups of twelve pulse pairs, with 30-microsecond spacing between pulse pairs, are transmitted with a recurrent frequency of 15 Hz. Fine bearing reference groups of six pulse pairs, with 24-microsecond spacing between pulse pairs, are also transmitted. Each coarse bearing reference group is followed by eight fine bearing reference groups to provide a total frequency of 135 Hz.

Distance reply pulse pairs are transmitted by the ground station in response to the interrogation pulse pairs transmitted by the TACAN set. The time delay between the transmission of the interrogation pulse and the reception of the reply pulse is measured to provide a reading of the distance between the aircraft and the ground station. Interrogation pulse pairs and the corresponding reply pulse pairs are transmitted at a rate of 30 pps in distance track operation, or 150 pps in distance search. A random jitter is superimposed on the pulse repetition frequency so that these pulses can be distinguished from similar pulses transmitted by other TACAN equipment.

The signal received from the ground station also includes distance reply pulses transmitted in response to interrogations from TACAN or DME equipment in other aircraft. Because of the random nature of these pulses, they cannot be mistaken for reply pulses intended for the subject aircraft. In order to maintain a constant duty cycle for the ground station transmitter and a consistent carrier for the bearing amplitude modulation, random filler pulses are transmitted during intervals when none of the other four signals are transmitted. These filler pulses provide an average prf of 2700 pps.

Bearing information signals are derived from amplitude-modulation of the signal pulses. Modulation is achieved by rotating a shaped radiating pattern around the transmitting antenna at a 15-Hz rate. The rotation of the pattern causes a variation in signal strength at any point that appears as amplitude modulation. The radiation pattern is such that the modulation



#	CONTROL	FUNCTION
1	FUNCTION SELECTOR	PWR ON-OFF: DETERMINES MODE OF OPERATION OF THE TRANSCEIVER: REC—RECEIVER (BEARING INFO ONLY) T/R —RECEIVER-TRANSMIT (BEARING & DME) A/A—AIR TO AIR (BEARING & DME)
2	CHANNEL SELECTOR	SETS FREQUENCY OF TRANSCEIVER AS PER CHANNELIZATION CHART TABLE 2-2
3	VOLUME CONTROL	SETS VOLUME OF TACAN SIGNAL TO ICS

228.203

Figure 2-28.—Typical TACAN Control Box.

envelope is a 15-Hz sine wave with a superimposed 135-Hz sine wave. (See fig. 2-24.)

Since the modulation of the signal is a result of rotating the radiation pattern, the phase of the modulation envelope is a function of the direction of the receiver from the transmitter. This phase is compared with the phase of the bearing reference signals previously discussed. A one-to-one relationship exists between the bearing angle and the phase angle of the 15-Hz modulation component. However, each degree of bearing angle produces a 9-degree phase angle in the 135-Hz component. The 15-Hz signal is therefore used as a coarse bearing measurement and the 135-Hz component is used for a fine measurement for improved accuracy.

The signal received by the TACAN set while operating in the receive mode is the same as that for the receive-transmit mode, except that no range interrogation pulses pairs are transmitted to the ground station and, therefore, no reply pulse pairs are received. This pulse pair would then be replaced by a filler pulse pair.

The signal received when operating in the air-to-air mode, in conjunction with a cooperating aircraft, consists of two groups: interrogation pulse pairs from the other aircraft, and reply pulses transmitted in response to interrogation

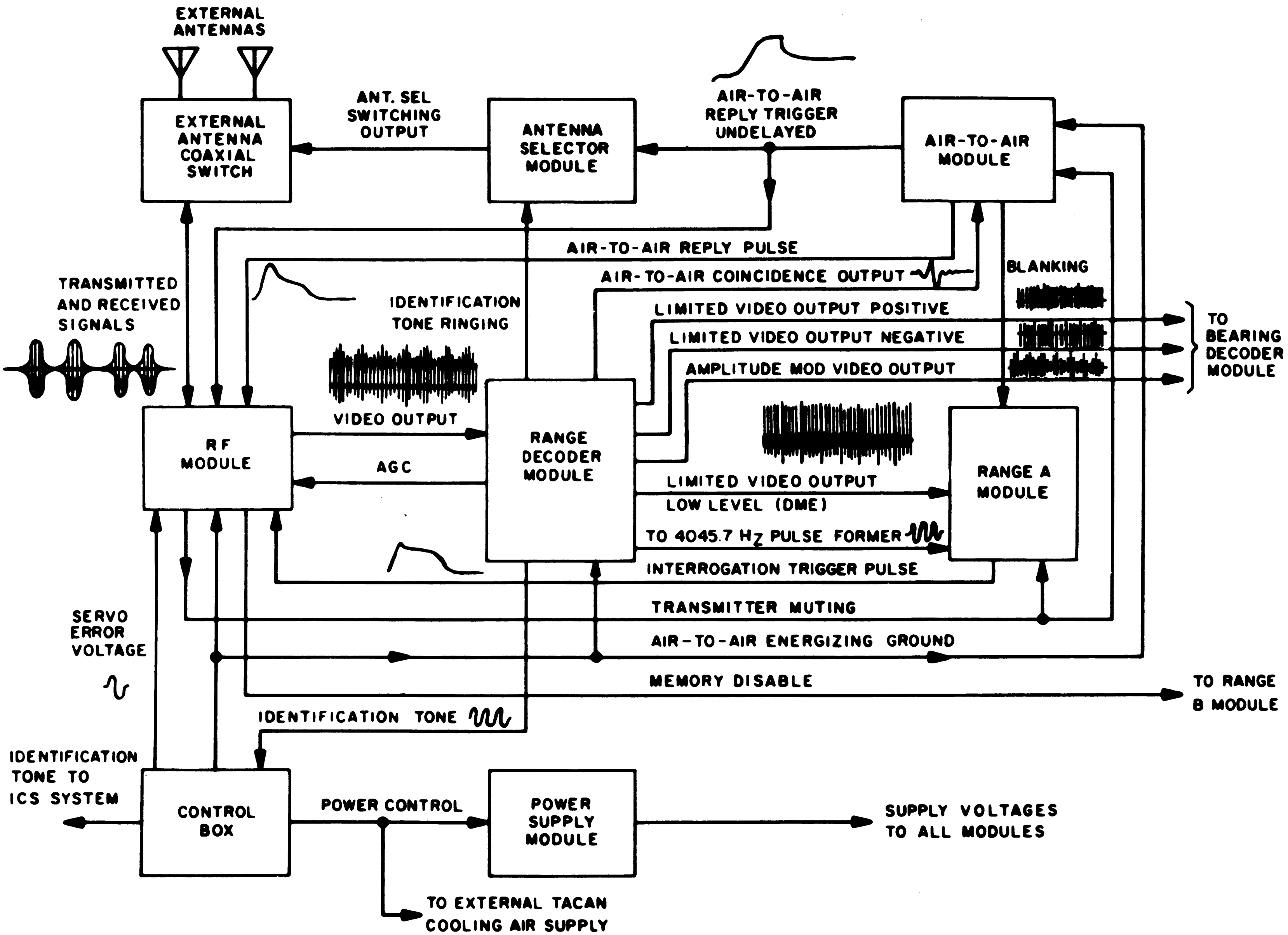

EXTERNAL ANTENNAS
EXTERNAL ANTENNA COAXIAL SWITCH
ANT. SEL SWITCHING OUTPUT
ANTENNA SELECTOR MODULE
AIR-TO-AIR REPLY TRIGGER UNDELAYED
AIR-TO-AIR MODULE
TRANSMITTED AND RECEIVED SIGNALS
AIR-TO-AIR REPLY PULSE
AIR-TO-AIR COINCIDENCE OUTPUT
BLANKING
IDENTIFICATION TONE RINGING
LIMITED VIDEO OUTPUT POSITIVE
LIMITED VIDEO OUTPUT NEGATIVE
AMPLITUDE MOD VIDEO OUTPUT
TO BEARING DECODER MODULE
VIDEO OUTPUT
RF MODULE
AGC
RANGE DECODER MODULE
LIMITED VIDEO OUTPUT
LOW LEVEL (DME)
TO 4045.7 Hz PULSE FORMER
RANGE A MODULE
INTERROGATION TRIGGER PULSE
SERVO ERROR VOLTAGE
TRANSMITTER MUTING
AIR-TO-AIR ENERGIZING GROUND
MEMORY DISABLE
TO RANGE B MODULE
IDENTIFICATION TONE
IDENTIFICATION TONE TO ICS SYSTEM
CONTROL BOX
POWER CONTROL
POWER SUPPLY MODULE
SUPPLY VOLTAGES TO ALL MODULES
TO EXTERNAL TACAN COOLING AIR SUPPLY

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Figure 2-30.—Receive-transmit function block diagram.

pulse pairs from the subject aircraft. The reply pulses are single pulses rather than pulse pairs so that they can be distinguished from the interrogation pulse pairs. A similar signal is also transmitted to the other aircraft by the TACAN set. The time delay between the transmitted interrogation pulse pair and the received reply pulse is used to measure the distance between the aircraft. (NOTE: No bearing information is possible.)

System Block Diagram Description

For the purpose of the system block diagram discussion, the TACAN Receiver-Transmitter is divided into three functional systems: the receive-transmit function, the range function, and the bearing function. The block diagrams for the three functions are described separately. An overall block diagram of the system is shown in figure 2-29 (foldout at the end of this chapter). (Correlate the three functional system diagrams with figure 2-29 during the following discussion.)

RECEIVE-TRANSMIT FUNCTION (figure 2-30).—The TACAN set operates with either of two antennas to prevent loss of signal due to shadowing of the antenna by the aircraft during rolls or banks. The RF module is connected to the antenna through a coaxial switch which is controlled by the antenna selector module. If the input signal to the RF module drops below a usable level, the switch is caused to alternate from one antenna to the other at a regular rate. When a usable signal is received from either antenna, the antenna selector module holds the antenna switch in position to maintain connection to that antenna.

The signal from the antenna is fed to the RF module where it is amplified and detected. The detected video is amplified and fed to the range decoder module where the range and bearing signals are separated. A limited video output signal, carrying range information, is fed to the range A module. Positive and negative limited video outputs and an amplitude-modulated video output are fed to the bearing decoder module to provide bearing information. An identification tone signal is fed from the range decoder module through a volume control in the Control Box to the aircraft intercom system. This signal provides an audible tone in International Morse code to identify the ground TACAN station in contact with the TACAN set installed in the aircraft. A ringing signal from the tuned ID tone filter is fed to the antenna selector module. The amplitude of this signal is used to determine the strength of the signal from the antenna in use. An AGC voltage, also developed in the range decoder module, is fed to the RF module to control the gain of the IF amplifiers.

When the TACAN set is operating in the receive-transmit mode, a 4045.7-Hz signal is generated in the range decoder module and fed to a pulse former circuit in the range A module. The pulse former output is fed to a countdown blocking oscillator. This circuit develops a timing pulse which initiates the interrogation trigger pulse. The interrogation trigger pulse is fed from the range A module to the modulator in the RF module. This pulse triggers an interrogation pulse pair which is transmitted to the ground station to obtain range information.

When the TACAN set is operating in the air-to-air mode, range interrogation pulse pairs received from the cooperating aircraft are detected by the range decoder module. The range decoder module then develops an air-to-air coincidence pulse which is fed to the air-to-air module. An air-to-air reply pulse is developed in the air-to-air module for transmission 50 microseconds after the interrogation pulse is received. The reply pulse is fed to the modulator in the RF module. The transmitter then sends a reply pulse to the other aircraft. A suppressor pulse, developed whenever an output pulse is transmitted, is available at a coaxial connector on the front panel of the Receiver-Transmitter. This pulse can be used to prevent interference in other equipment in the aircraft operating at or near the TACAN frequency. A second coaxial connector on the front panel can be used to feed suppressor pulses into the TACAN set to prevent interference caused by other transmitters in the aircraft.

Since no ID tone is available when the equipment is operating in the air-to-air mode, another signal must be provided to operate the antenna selector circuits. For this purpose, the undelayed air-to-air reply trigger is fed from the air-to-air module to the antenna selector module. This pulse is also fed to the RF module to blank the

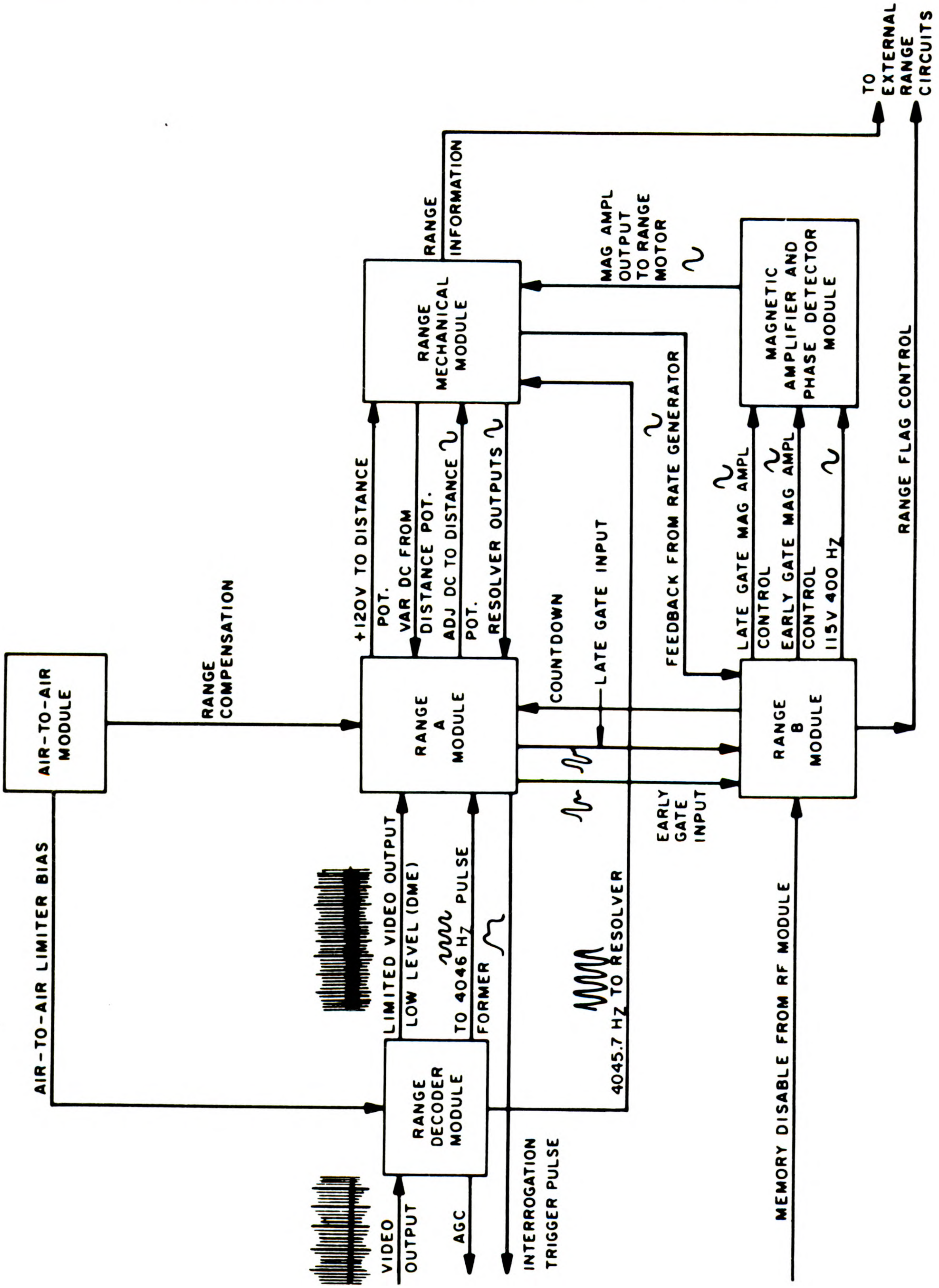

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Figure 2-31.—Range function block diagram.

interrogation pulse modulator circuits, thereby preventing simultaneous transmission of the reply pulse and an interrogation pulse pair. The mode of operation and the desired RF channel are selected by the switches on the Control Box. With the function selector switch in the OFF position, all circuits of the equipment are deenergized. In each of the other positions, the function selector switch operates relays in the mount, which connect 115-V, 400-Hz power to the power supply module. The relay-controlled power is also available to regulate an external cooling air blower. Since operation of the transmitter and range function circuits are not required for the receive mode, only standby power is supplied to the range A module, the air-to-air module, the range mechanical module, and the transmitter high-voltage power supply while in this mode.

In the air-to-air mode, a ground connection is made to circuits in the air-to-air module and the range decoder module to energize the circuits used for the air-to-air mode. A blanking voltage is developed in the air-to-air module whenever the equipment is switched between the air-to-air mode and the receive-transmit mode. This voltage is fed to the range A module to blank the triggers to the transmitter modulator during the transition between modes.

Selection of the frequency channel is made with the channel selector knob on the Control Box. Movement of this knob causes a servo error voltage to be applied to the tuning servo in the RF module. The servo system then selects the proper oscillator crystal and tunes the transmitter and receiver circuits to the selected channel frequency. A transmitter muting voltage is developed in the RF module while the servo is operating. This voltage is applied to the modulator to blank operation of the triggering circuits. This prevents transmitter operation while the RF circuits are being tuned.

RANGE FUNCTION (figure 2-31).—Range interrogation pulses are timed by a 4045.7-Hz signal from the range decoder module. This signal is fed to a pulse former circuit and countdown circuit in the range A module, which develops an interrogation trigger pulse. The interrogation trigger pulse has a pulse repetition frequency of 150 pps in search operation or 30 pps in range tracking, and is synchronized by the 4045.7-Hz signal. The interrogation trigger pulse is fed to the RF module to trigger the transmission of an interrogation pulse pair.

The received video signal from the RF module is fed to an amplitude limiter circuit in the range decoder module. The limited video output contains the range reply pulse and many random pulses. In order to select the reply pulse, early gate and late gate pulses are generated in the range A module. The repeated coincidence of the reply pulse with either gate pulse produces an output which is fed to the range B module. The gate pulses are delayed from the interrogation trigger pulse by a time proportional to the range measurement. Since the correct reply pulse is the only one with a consistent time relationship to the interrogation pulse, it is the only pulse that can be repeatedly coincident with a gate pulse.

Early and late gate coincidence inputs from the range A module are processed by the range B module to develop a control signal for the range magnetic amplifier in the magnetic amplifier and phase detector module. The 115-V, 400-Hz power for the magnetic amplifier is also fed through the range B module. The output of the magnetic amplifier controls the operation of the range servo motor in the range mechanical module. A rate generator output from the range mechanical module is applied as negative feedback to the range B module magnetic amplifier control circuit for servo stability.

The time delay between the interrogation trigger pulse and the early gate and late gate pulses is determined by the combined outputs of a distance potentiometer and a resolver coupled to the range servo motor. The potentiometer energizing voltage, + 120 V dc, is obtained from the range A module. The potentiometer output from the wiper arm is fed to a phantastron circuit in the range A module to set the delay time for the gating circuit.

The resolver input is obtained from the 4045.7-Hz oscillator in the range decoder module. The output of the resolver is used to provide a phase shifted 4045.7-Hz signal for the range A module. This phase shift is used in conjunction with the phantastron delay to time the gate generator circuits.

Additional outputs of the range mechanical module provide range information to external circuits and indicators. These outputs are supplied by synchro transmitters and potentiometers mechanically coupled to the distance measuring potentiometer. The outputs are therefore proportional to the range measurement.

If an insufficient number of gate coincidence pulses are developed while tracking in range, a memory circuit in the range B module causes the range circuits to hold the last measurement for about 10 seconds and develops a range flag control output which is fed to the range indicators. The flag control signal is used to operate a warning flag to signify that the range information being presented is unreliable. If the range signal returns before the end of the 10-second period, the range flag control output is removed and range tracking is resumed. If no range gate coincidence pulses are received, the range circuits automatically switch into search operation.

When the RF module servo is operating to change the channels, a memory disable signal is fed to the memory circuits in the range B module. This signal disables the memory circuit and causes the range circuits to transfer immediately to search operation. When the range circuits are in search operation, a ground connection is made in the range B module, which is coupled to the countdown circuit in the range A module. This connection is used to change the pulse repetition frequency of the interrogation trigger pulses from 30 pps, as used in track, to 150 pps for search operation.

The time delay between the interrogation pulse and the reply pulse, introduced by the air-to-air circuit, differs slightly from that introduced by the ground beacon. Since the range measurement is dependent on the delay, a range correction must be added in the air-to-air mode of operation. This correction is achieved by connecting a phase shifting network in the air-to-air module to the gate timing circuits in the range A module. This network shifts the phase of the 4045.7-Hz signal used to trigger the early gate circuits to change the timing of the gate pulses.

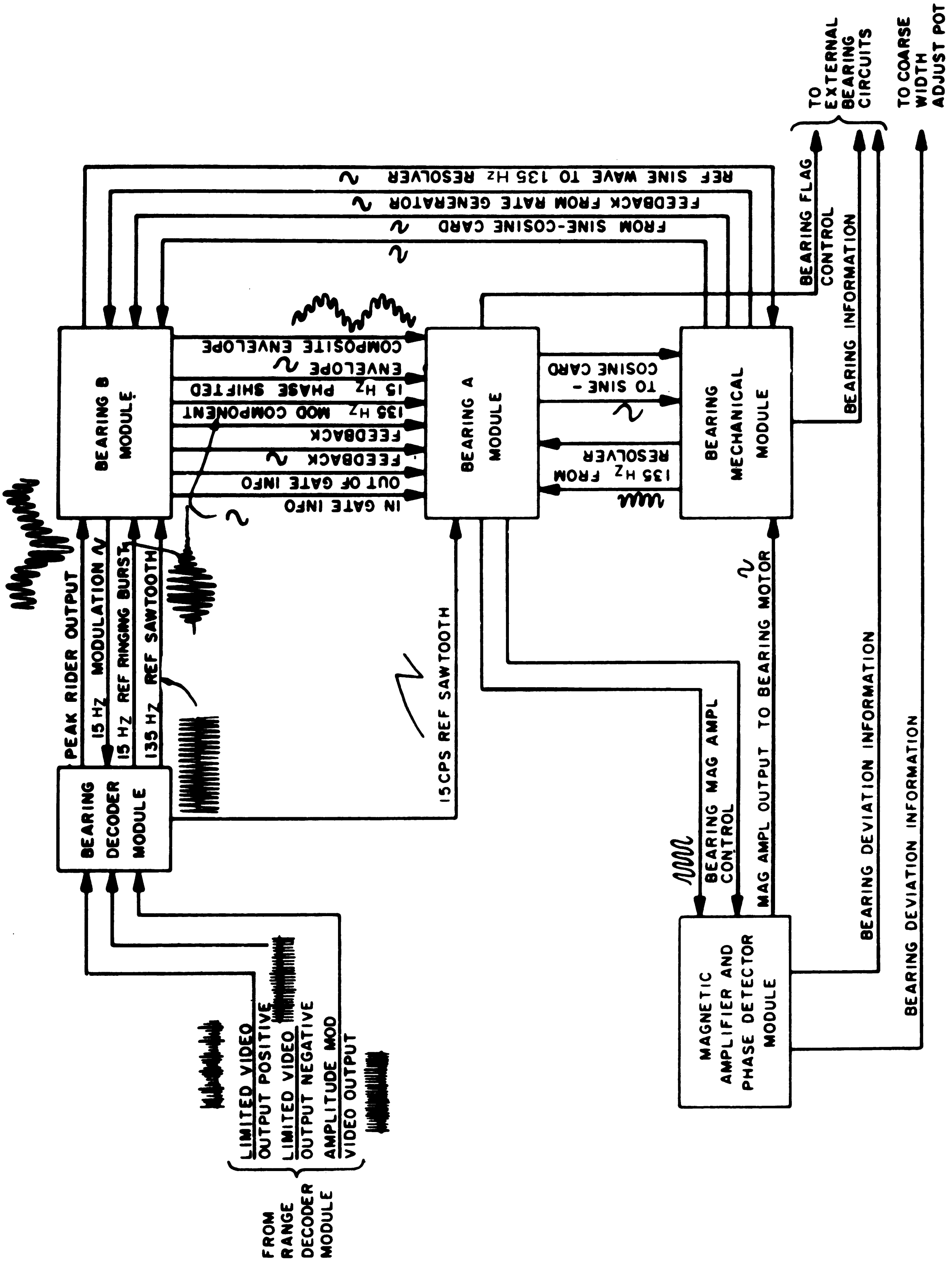
The self-bias developed in the video limiter circuit of the range decoder module is a function of the received prf. The prf received in the air-to-air mode of operation is considerably less than in either the receive or the receive-transmit mode. The correct self-bias will, therefore, not be developed in the air-to-air mode. To ensure correct limiter operation, a negative bias voltage is fed to the limiter circuit from the air-to-air module when operating in the air-to-air mode. This bias voltage is disconnected in the receive or receive-transmit mode.

BEARING FUNCTION (figure 2-32).—The video signals required to provide bearing information, such as limited video positive, limited video negative, and the amplitude-modulated video signals, are fed from the range decoder module to the bearing decoder module. The bearing reference bursts are extracted from the negative limited video and are used to gate those bursts out of the amplitude modulated signal. The modulation envelope is detected by a peak rider circuit and fed to the bearing B module, amplified, and then fed to the bearing A module.

For bearing search operation, the 15-Hz signal containing the coarse bearing information is separated from the composite modulation envelope in the bearing A module. The 15-Hz signal is then fed to a phase splitter and the output is applied to a sine-cosine potentiometer in the bearing mechanical module. The sine-cosine potentiometer is mechanically coupled to a bearing servo motor to position the shaft in proportion to the bearing measurement.

The output of the sine-cosine potentiometer is fed to a phase shifting network in the bearing B module. The output of this network is a 15-Hz signal shifted through a phase angle equal to the angle of rotation of the sine-cosine potentiometer shaft. This output is fed to a phase comparison circuit in the bearing A module.

The 15-Hz reference bursts are separated from the limited video positive signal in the bearing decoder module and are used to develop a 15-Hz reference sawtooth waveform. This waveform is fed to the bearing A module where the 15-Hz sine wave component is extracted by a filter circuit. The 15-Hz reference signal phase is then compared with the phase of the phase-shifted 15-Hz modulation component.


BEARING B MODULE
BEARING A MODULE
BEARING MECHANICAL MODULE
BEARING DECODER MODULE
MAGNETIC AMPLIFIER AND PHASE DETECTOR MODULE
REF SINE WAVE TO 135 Hz RESOLVER
FEEDBACK FROM RATE GENERATOR
FROM SINE-COSINE CARD
COMPOSITE ENVELOPE
ENVELOPE
15 Hz PHASE SHIFTED
135 Hz MOD COMPONENT
FEEDBACK
FEEDBACK
OUT OF GATE INFO
IN GATE INFO
TO SINE - COSINE CARD
135 Hz FROM RESOLVER
BEARING FLAG CONTROL
BEARING INFORMATION
TO EXTERNAL BEARING CIRCUITS
TO COARSE WIDTH ADJUST POT
PEAK RIDER OUTPUT
15 Hz MODULATION
15 Hz REF RINGING BURST
135 Hz REF SAWTOOTH
15 CPS REF SAWTOOTH
BEARING MAG AMPL CONTROL
MAG AMPL OUTPUT TO BEARING MOTOR
BEARING DEVIATION INFORMATION
BEARING DEVIATION INFORMATION
LIMITED VIDEO OUTPUT POSITIVE
LIMITED VIDEO OUTPUT NEGATIVE
AMPLITUDE MOD VIDEO OUTPUT
FROM RANGE DECODER MODULE

228.207

Figure 2-32.—Bearing function block diagram.

Any phase difference causes a control signal to be developed, which is fed to the bearing magnetic amplifier. The magnetic amplifier output drives the bearing servo motor to position the sine-cosine potentiometer for a zero phase difference.

The phase-shifted 15-Hz signal is also fed to a 40-degree gate circuit in the bearing B module for comparison with the 15-Hz reference burst from the bearing decoder module. When less than ±20 degree phase error exists, an in-gate signal permits switching the bearing circuits to bearing track, using the 135-Hz information. A bearing flag control signal is developed in the bearing A module when the circuits are operating in bearing search. This signal is fed to the external bearing indicators to indicate that the bearing information is unreliable. (The indicator works the same as the VOR indicator previously described.)

In bearing track operation, a 135-Hz reference sawtooth wave, triggered by the 135-Hz reference pulses, is developed in the bearing decoder module and fed to the bearing B module. The 135-Hz fundamental sine wave is extracted from the reference sawtooth in the bearing B module and is fed to the 135-Hz resolver in the bearing mechanical module. The resolver is mechanically coupled to the bearing servomotor to position the shaft in proportion to the bearing measurement.

The output of the 135-Hz resolver is fed to a phase-shifting and summing network in the bearing A module. The output of this circuit is a 135-Hz reference sine wave shifted through a phase angle equal to the angle of rotation of the resolver shaft. This output is fed to a phase comparator circuit.

The 135-Hz component of the modulation signal is separated from the composite signal in the bearing B module and is fed to the phase comparator circuit in the bearing A module for comparison with the phase-shifted 135-Hz reference signal. Any phase difference causes an error signal to be fed to the bearing magnetic amplifier in the magnetic amplifier and phase detector module. The magnetic amplifier output is used to drive the bearing servomotor as in bearing search operation.

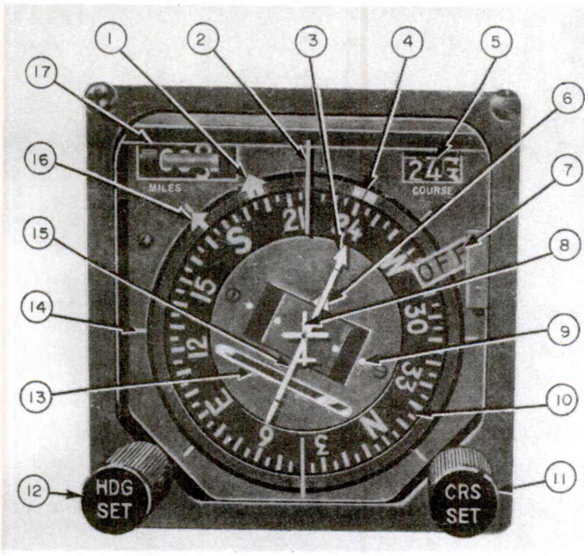
The 15-Hz phase-shifted modulation is fed from the bearing B module to the bearing decoder module to control the bias of the 15-Hz reference burst decoder. If the amplitude of the phase-shifted modulation signal falls below a minimum level, the reference burst decoder is disabled. Loss of the reference burst output causes the bearing circuits to be switched to search operation.

A rate generator output from the bearing mechanical module is fed back through the bearing B module to the magnetic amplifier control tube in the bearing A module. A relay on the bearing B module selects the phase of the feedback to produce a positive feedback in bearing search operation and negative feedback in bearing track operation. The positive feedback helps to increase the search rate to minimize the time required for search. The negative feedback in track operation increases servo stability to improve the bearing accuracy.

Bearing information signals from a differential servo transmitter in the bearing mechanical module are fed to external bearing indicators to provide a visual indication of the bearing measurement. Bearing deviation information from the magnetic amplifier and phase detector module provides an indication of the difference between the desired bearing, set manually at the indicator, and the bearing measurement. A coarse width adjustment potentiometer on the front panel of the Receiver-Transmitter adjusts the range of allowable deviation by setting the amplitude of the deviation signal. (Note: The course deviation indicator and course indicator used with TACAN operate the same as those previously described for VOR.)

Alternate TACAN Instrumentation

Another instrument which is used for displaying TACAN information is the horizontal situation indicator (HSI). (See figure 2-33.) This instrument combines all of the information



1. **Bearing pointer No. 2 (ADF).**
2. **Top lubber line.**
3. **Selected course arrow.**
4. **Heading select marker.**
5. **Selected course counter.**
6. **To-From arrow.**
7. **Power off warning flag.**
8. **Aircraft symbol.**
9. **Course dot.**
10. **Compass card.**
11. **Course select knob.**
12. **Heading select knob.**
13. **Course bar slot.**
14. **Fixed index.**
15. **Course bar.**
16. **Bearing pointer No. 1 (TACAN).**
17. **Distance counter.**

243.154

Figure 2-33.—Horizontal situation indicator (HSI).

previously displayed on three indicators (course indicator, course deviation indicator, and DME) into a single indicator presentation. It is presently installed in most of the latest Navy aircraft.

Aircraft heading information is displayed on the compass card and read from the top lubber line. Automatic Direction Finder (ADF) information may be displayed on the No. 2 pointer, and TACAN station bearing information is usually on the No. 1 pointer. The selected course arrow and the heading select marker are manually set by knobs, pictured as CRS SET and HDG SET, respectively, at the lower corners of the HSI. The course in degrees is displayed in the COURSE window. The course bar indicates the displacement from the manually preselected course arrow. The position of the TO-FROM arrow in the center of the HSI shows whether or not the aircraft will, while maintaining the selected course, fly a track To or From the station and, as previously discussed, is often limited to about 200 miles. The range in miles is displayed in the MILES window up to 199.9. A mask covers the numerals when the range indication is unreliable or is not in use.

In the absence of the HSI, TACAN problems would be flown using RMI, course indicator, and DME instruments in coordination.

ELECTRONIC ALTIMETERS

Airborne electronic altimeters (commonly called radar altimeters) are absolute altimeters because they measure and indicate the height (altitude) of the aircraft above the terrain, rather than with respect to sea-level, as do barometric altimeters. They may operate on frequency-modulation principles (FM), pulse modulation principles or a combination of both. Most modern radar altimeters utilize pulse-modulation principles.

Because they operate by transmitting and receiving radio-frequency (RF) energy, they are accurate over all types of terrain, and under all types of weather conditions.

BASIC SYSTEM PRINCIPLES

A typical radar altimeter system operates on the accurate timing of the interval required for an RF pulse to travel from the aircraft's transmitting antenna to the terrain below, and return to the aircraft's receiving antenna. The system converts the time interval to a range signal that is used as the input to various readout circuits. Basic functions of the radar altimeter system are

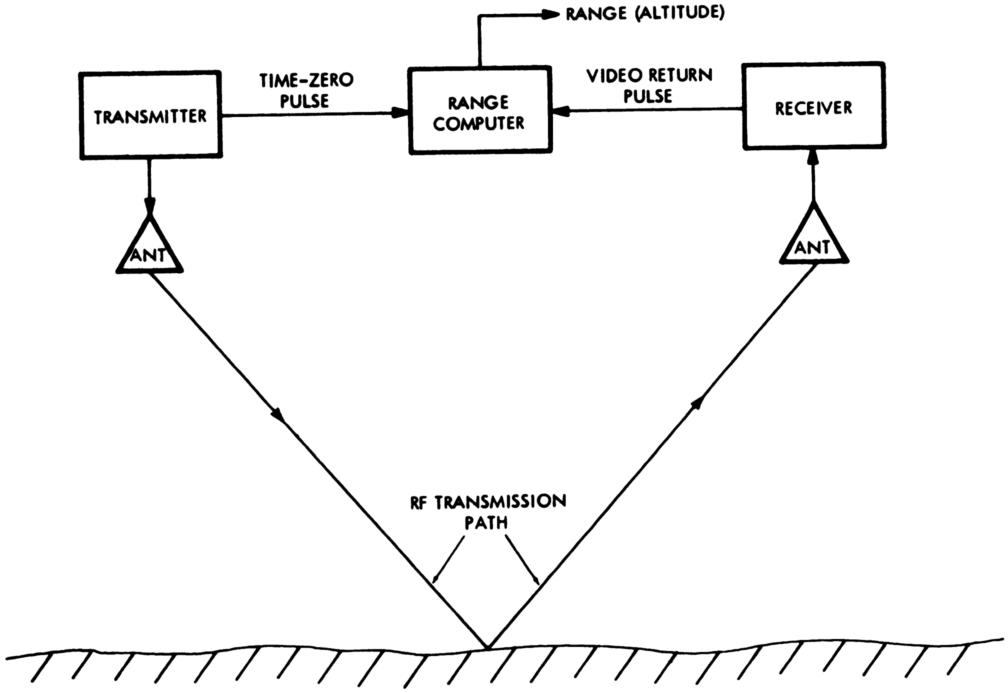


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Figure 2-34.—Basic elements of radar altimeter system.

illustrated in figure 2-34. When the transmitter fires, it transmits a pulse of RF energy out the transmitting antenna and at the same time generates a time-zero (T-zero) pulse which is used to start the measurement of the transmission-reception time interval. The time measuring circuit is commonly called the range computer or tracker. When the RF return (echo) pulse arrives at the receiver, a video return pulse is generated. A track gate (which is generated in the range computer by the T-zero pulse) is positioned on the leading edge of the video return pulse, which in turn causes the output of the range computer to be an analog signal that represents range or altitude. The output of the range computer may also be in the form of a bit digital word, which is used by some system readout indicators.

Closed Loop Tracking

Typically, most radar altimeter R-T units use a closed loop tracking system contained in the unit's range computer. For explanation purposes we'll analyze the closed-loop tracking system used by the APN-194 range computer. (See figure 2-35.) NOTE: The APN-194 maximum altitude readout is 5,000 feet.

Each time the transmitter fires, a time zero pulse is generated. This pulse triggers the ramp generator, which generates a ramp voltage that varies linearly from 0 to 28 volts in 10.17 μsec. (Time required for RF energy to travel 10,000 feet; that is, to echo from a 5,000 foot altitude.)

At the same time an internal range voltage is being swept from 0.5 to 32 volts at a relatively slow rate (2 to 3 times a second). When these two voltages coincide at the comparator, a track gate pulse is generated and appears at one input to the track gate. The level that the ramp voltages reach at the time the track gate pulse is generated, is proportional to altitude or range. When a track gate pulse and a video return pulse occur simultaneously (in time) at the track gate inputs, a track gate output pulse is generated, which controls the value of the internal range voltage. The internal range voltage at the instant the track gate output pulse is generated represents

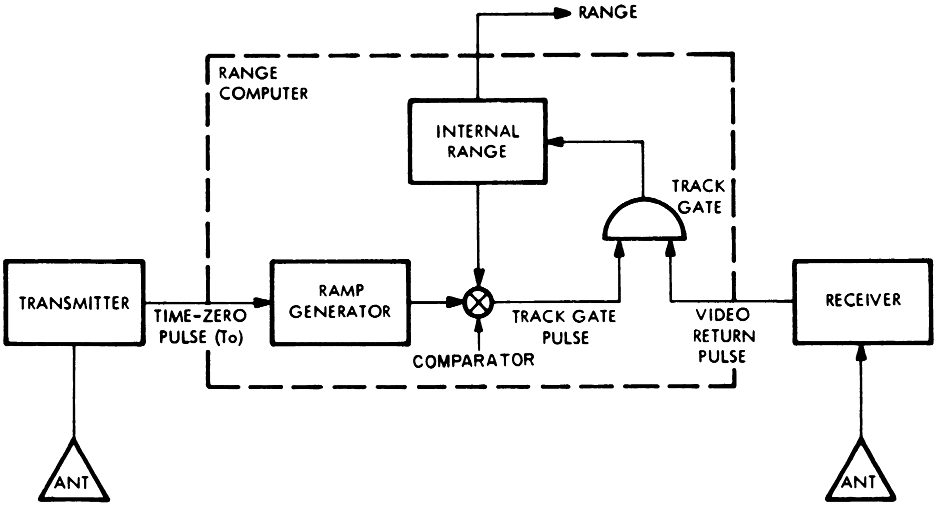

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Figure 2-35.—Basic closed loop of range computer.

the radar range (altitude). This output is applied to an indicator readout unit servo-system which drives the indicator needle.

Leading Edge Tracking

When the track gate pulse is applied coincidentally with the video return pulse, the track gate output consists of the overlapping portion of the track gate pulse and the video return pulse. Figure 2-36 shows various possible time relationships of the two pulses. When the altimeter system is properly tracking the RF echo, the track gate output (shaded area) will be as illustrated in figure 2-36(c). The track gate output will consist of pulses, at a rate of 8,500 pulses per second (transmitter firing rate,) with individual values (amplitude) equal to the overlapping (shaded) portion of the two pulses. The track gate output pulses are then processed to maintain a constant overlap of the track gate and video pulses. If the RF transmission path distance should change (height above terrain) the track gate output pulse values would also change. This change in the track gate output pulse will change the internal range voltage, which in turn will change the position (time) of the track gate. (NOTE: The track gate pulse would occur at a different time because the ramp generator would have a different time to reach the new voltage value of the internal range voltage.) In this manner the conditions of figure 2-36(c) are maintained.

You will notice that the trailing edge of the track gate pulse intercepts the leading edge of the video return at the approximate midpoint. This characteristic is called "leading edge tracking." By controlling the amplitude of the video return pulse so that it has a constant amplitude under all conditions (altitude, attitude, terrain, etc.) and by controlling the position of the track gate with respect to the leading edge of the return video, the radar altimeter system is made essentially independent of all characteristics except the clearance of the aircraft over the terrain.

Figure 2-37 shows the basic functions of the leading edge closed loop portion of the range computer. As previously mentioned, a track gate pulse is generated whenever the ramp generator voltage and the internal range voltage are equal at the comparator. The internal range voltage can be changed from 0.5 volt to 32 volts only relatively slowly by track error current inputs, and will hold its value whenever the track error current becomes zero. The ramp generator voltage also changes from zero volts to 28 volts. However, this voltage changes linearly in 10.17 microseconds, as previously explained. This ramp is generated each time the altimeter's transmitter fires (8,500 pps). Figure 2-38 shows

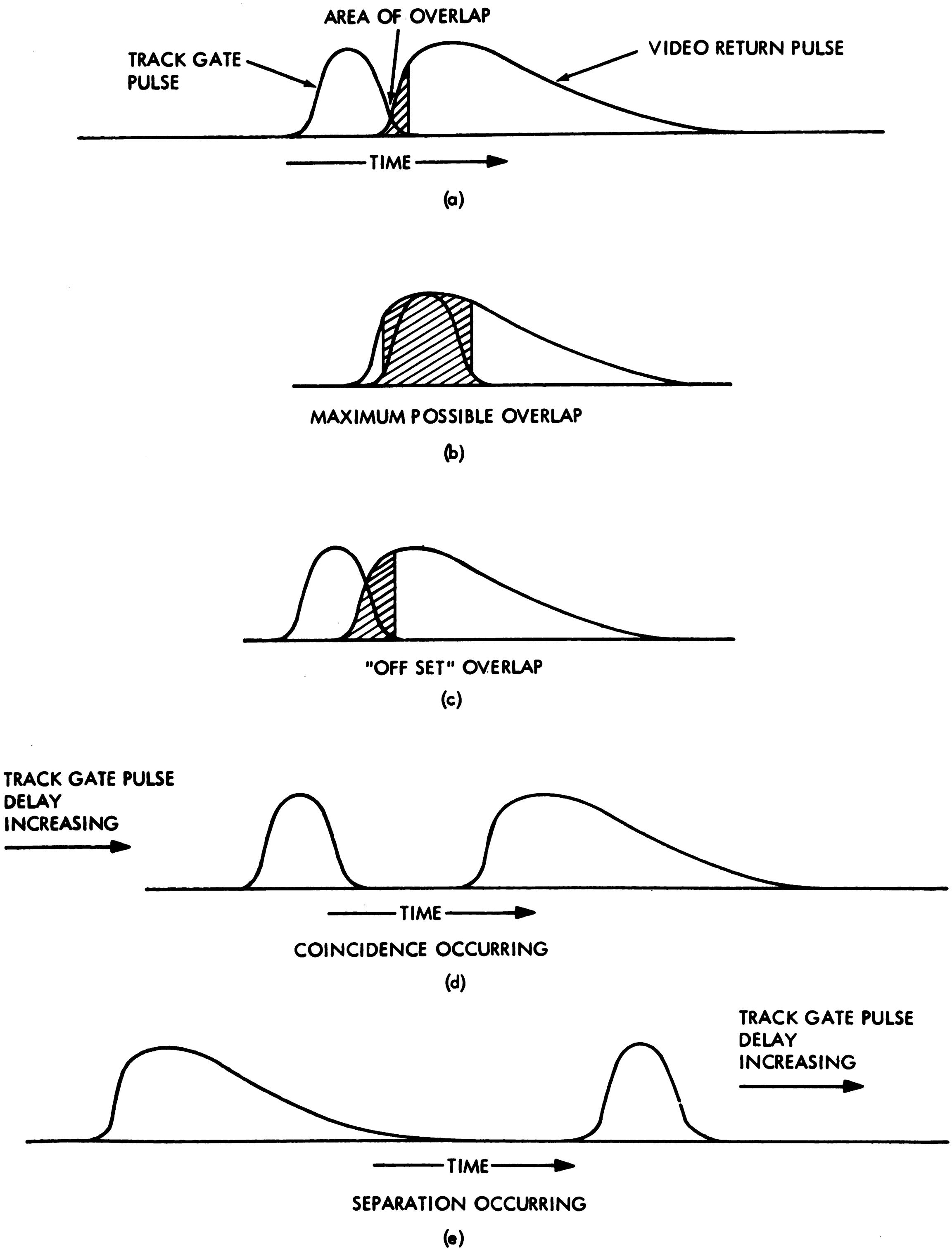

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Figure 2-36.—Various pulse relationships.

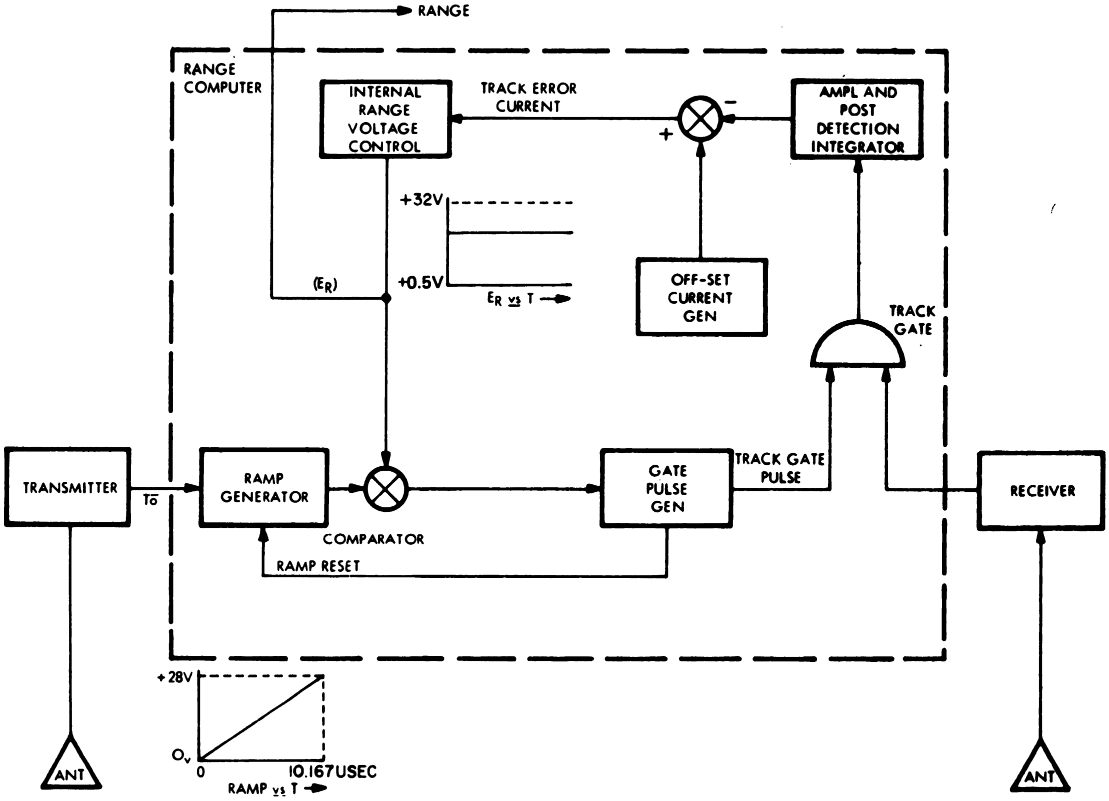

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Figure 2-37.—Radar altimeter system—tracking elements.

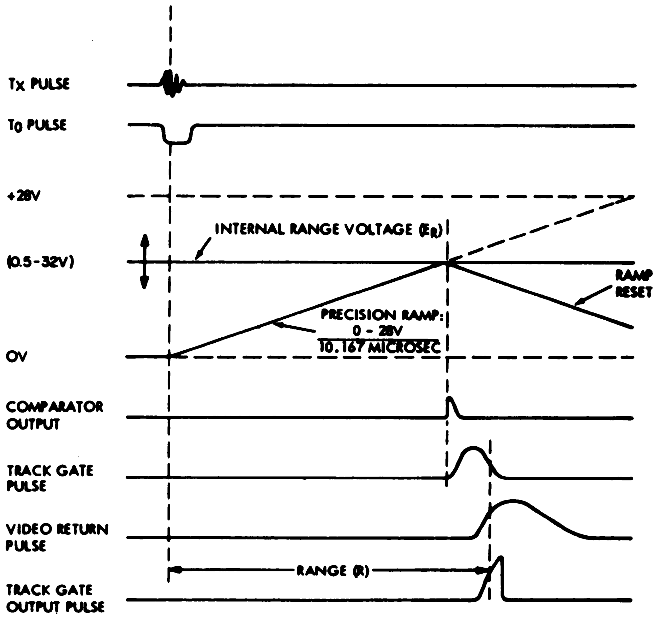

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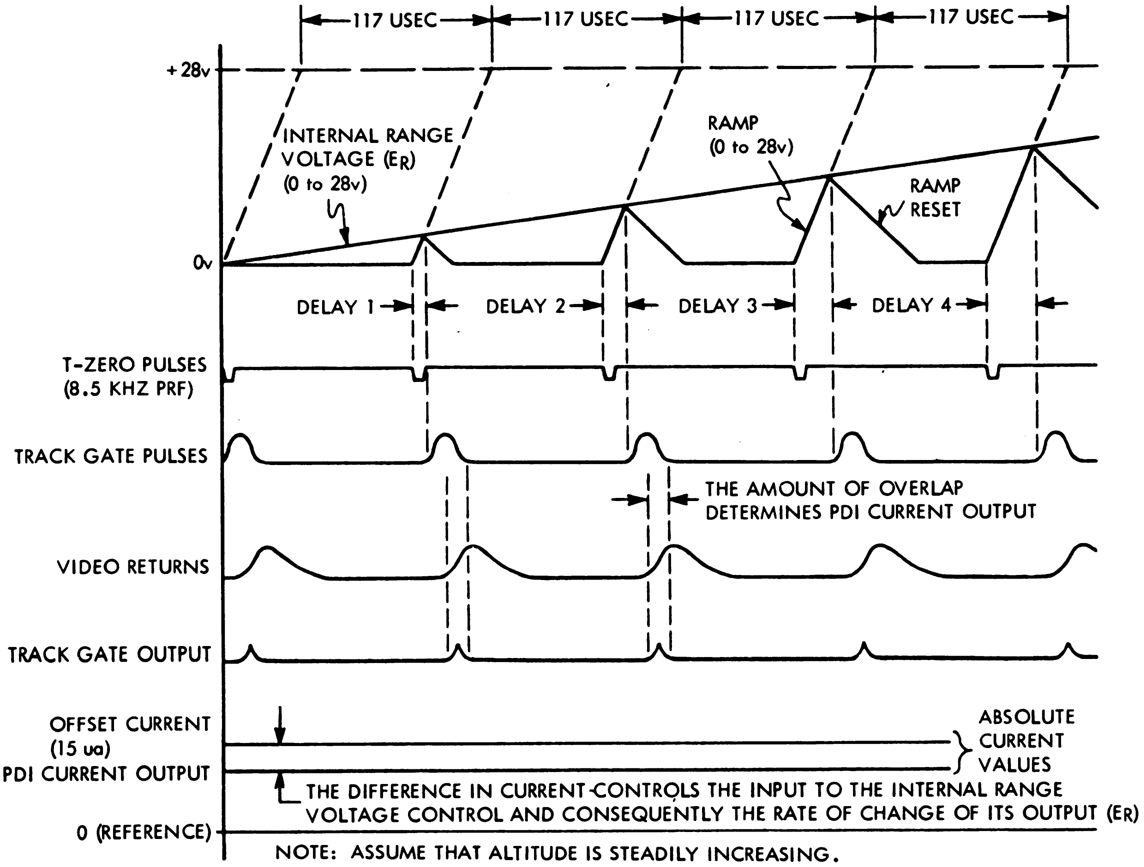
Figure 2-38.—Developing track gate output.

the sequence of events and the voltage relationships at the comparator during one transmission cycle. A comparator output pulse is generated each time the ramp generator and internal range voltages are equal. When the comparator output pulse occurs, a track gate pulse is generated. Each time a track gate pulse is generated, a ramp reset signal is also fed back to the ramp generator (see figure 2-37) commanding the generator to return to zero.

To keep the trailing edge of the track gate pulse intercepting the midpoint of the video return pulse, (see figure 2-37) the video leading edge output pulses from the track gate, are amplified, filtered, and summed with an off-set current to produce an error current to control internal range voltage. When the track gate pulse overlaps the leading edge of the video return signal by the amount desired, the output of the amplifier and post detection integrator (pdi) will be 15 microamperes current. The off-set current is a negative 15 microamperes current. Therefore, under ideal conditions, the track error current to the internal range voltage control will be zero. Consequently, the time delay used in generating the track gate pulse (the time for the ramp generator to reach the value of the internal range voltage) will not change.

When the altitude of the aircraft increases gradually (see figure 2-39) the amount of overlap between the track gate pulse and video return pulse decreases (video arrives later) with each succeeding return video pulse applied to the track gate. Consequently the output of the


117 USEC
117 USEC
117 USEC
117 USEC
+28v
0v
INTERNAL RANGE VOLTAGE (ER) (0 to 28v)
RAMP (0 to 28v)
RAMP RESET
DELAY 1
DELAY 2
DELAY 3
DELAY 4
T-ZERO PULSES (8.5 KHZ PRF)
TRACK GATE PULSES
THE AMOUNT OF OVERLAP DETERMINES PDI CURRENT OUTPUT
VIDEO RETURNS
TRACK GATE OUTPUT
OFFSET CURRENT (15 ua)
PDI CURRENT OUTPUT
ABSOLUTE CURRENT VALUES
THE DIFFERENCE IN CURRENT-CONTROLS THE INPUT TO THE INTERNAL RANGE VOLTAGE CONTROL AND CONSEQUENTLY THE RATE OF CHANGE OF ITS OUTPUT (ER)
0 (REFERENCE)
NOTE: ASSUME THAT ALTITUDE IS STEADILY INCREASING.

228.213

Figure 2-39.—Track loop relationships.

amplifier and pdi function decreases from 15 microamperes and the track error current out of the summation network becomes negative (some negative portion of the negative off-set current). This negative input to the internal range voltage control is phased to cause the internal range voltage to increase and more time will be required for the ramp generator voltage to equal it. The result is that the track gate pulses follow the leading edge of the received signals at the track gate.

When the altitude of the aircraft decreases, the overlap of the track gate pulse with the video return pulse increases. (The signal arrives sooner, so more of the video is in the gate.) (See figure 2-36.) The output of the amplifier and pdi function then becomes greater than the 15 microamperes. The track error current becomes positive out of the summation network, causing the internal range voltage to decrease. The ramp generator voltage will reach this new value sooner. Therefore the track gate pulse will be generated sooner and, with decreasing altitude, the echo signal would still be tracked.

Gain Control

The accuracy of the radar altimeter altitude measurement is dependent, not only on the slope and linearity of the ramp generator voltage, but also on the consistency of the rise time of the video return pulse. The purpose of an altimeter's gain control system is to keep the rise time of the video return pulse the same under all received signal strength conditions. Figure 2-40 shows the relationship of the gain control function and the tracking/search mode control function. There are two system gain control functions: signal strength controlled, and range controlled. The signal controlled gain consists of noise automatic gain control (nagc) and keyed automatic gain control (kagc). Range controlled gain consists of sensitivity range control (src) and sensitivity range control assist.

The receiver's IF gain control system is phased so that the gain of the IF amplifier increases with decreasing signal strength. (Refer to figure 2-40.) One input to the IF gain control system is the internal range voltage which is used

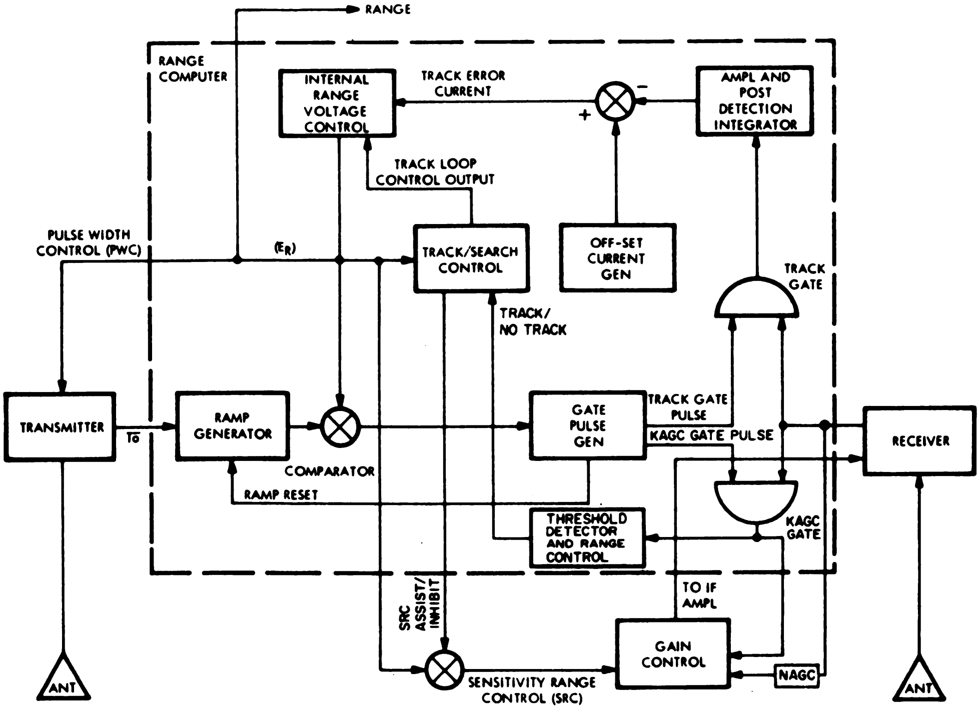


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Figure 2-40.—Gain and track search mode control.

to drive the sensitivity range control (src). Its gain schedule is a nonlinear function of altitude, decreasing the receiver's sensitivity only at very low altitudes to prevent false tracking of the transmitter antenna leakage pulse (stray radiation). There are two gain controlling sources from the range computer: nagc and kagc. The nagc is a wide band control used to sense all noise and video signals from the receiver's IF amplifier. It will limit the IF gain to maintain a usable signal-to-noise ratio. The kagc circuit is a fully keyed (gated) circuit. That is, it allows only those IF signals which occur during the kagc pulse to control IF amplifier gain. The kagc pulse is generated simultaneously with the track gate pulse. However, the kagc pulse is wider than the track gate pulse and therefore it overlaps much more of the video return pulse than does the track gate pulse. (It must include the video pulse peak.) The function of the kagc circuit is to control the receiver's IF gain so that the peak of the video pulse remains constant under all conditions of signal strength.

The sensitivity range control (src) is assisted during the search mode of operation. Because the IF gain control circuit has a time constant of approximately 50 milliseconds, it cannot react fast enough to reduce the IF gain during the rapid 20-millisecond retrace cycle of the internal range generator. If not compensated, the increased sensitivity would allow the system to begin tracking antenna stray radiation signals because the IF gain would be relatively high as the track/search control caused the internal range voltage to begin its outbound sweep. Therefore, during the retrace the src (provided by an output from the track/search control) forces the IF gain control to reduce the IF gain; consequently receiver sensitivity before the retrace ends and the outbound sweep begins.

Mode Control

The previous discussion has assumed that the system was tracking an echo pulse. In actual operation the system is either in an automatic mode or the self-test mode. The automatic mode contains three sub modes: track, search, and memory, during which the system searches for an echo pulse or tracks that pulse. The self-test mode is manually commanded and fully exercises the automatic mode, causing the system to acquire and track a synthetic target and display a 100-foot range. The automatic mode control system receives its input from the kagc circuit and the mode of operation is determined by the video return pulse. If 8 to 10 consecutive video return pulses have sufficient amplitude, the mode control will not modify the tracking mode if the system is tracking, and will switch to track if it is searching. The mode control first switches to the tracking operation when 8 to 10 consecutive synchronous video pulses, of 6 volts amplitude or greater, are applied to the kagc gate. The time constant of the track/no track detector of the track/search control circuit is selected so that it will require 8 to 10 pulses before its output will exceed the tracking threshold. This prevents the system from being switched into the track mode by random pulses from other systems operating in the area.

The mode control has a 0.2-second hold condition to provide for momentary drops in signal strength. If the video return pulse does not return to sufficient strength within the 0.2-second interval, the mode control enables a memory mode of operation. The memory mode lasts for approximately one second, during which time the internal range circuits search for a new target and the last valid external range output is maintained. If a new target is detected during the memory mode, the system reverts to the normal track mode. If a target is not detected, the system switches to the search mode. During the search mode, the track/search control overrides and controls the track loop. The track loop current is removed from the internal range control circuits and the track/search control forces the internal range voltage through its limits of 0.5 to 32 volts at about three times a second (the search out rate is about 15,000 to 20,000 feet per second). This causes the kagc and track gate pulses to run through their full range of delays seeking to find the video return pulse. During the search retrace portion of the cycle, the track/search control is inhibited from switching to the track mode of operation. This assures that the system will not acquire a secondary target (one having greater range than the primary target) during the retrace cycle. Figure 2-41 shows the search and acquisition

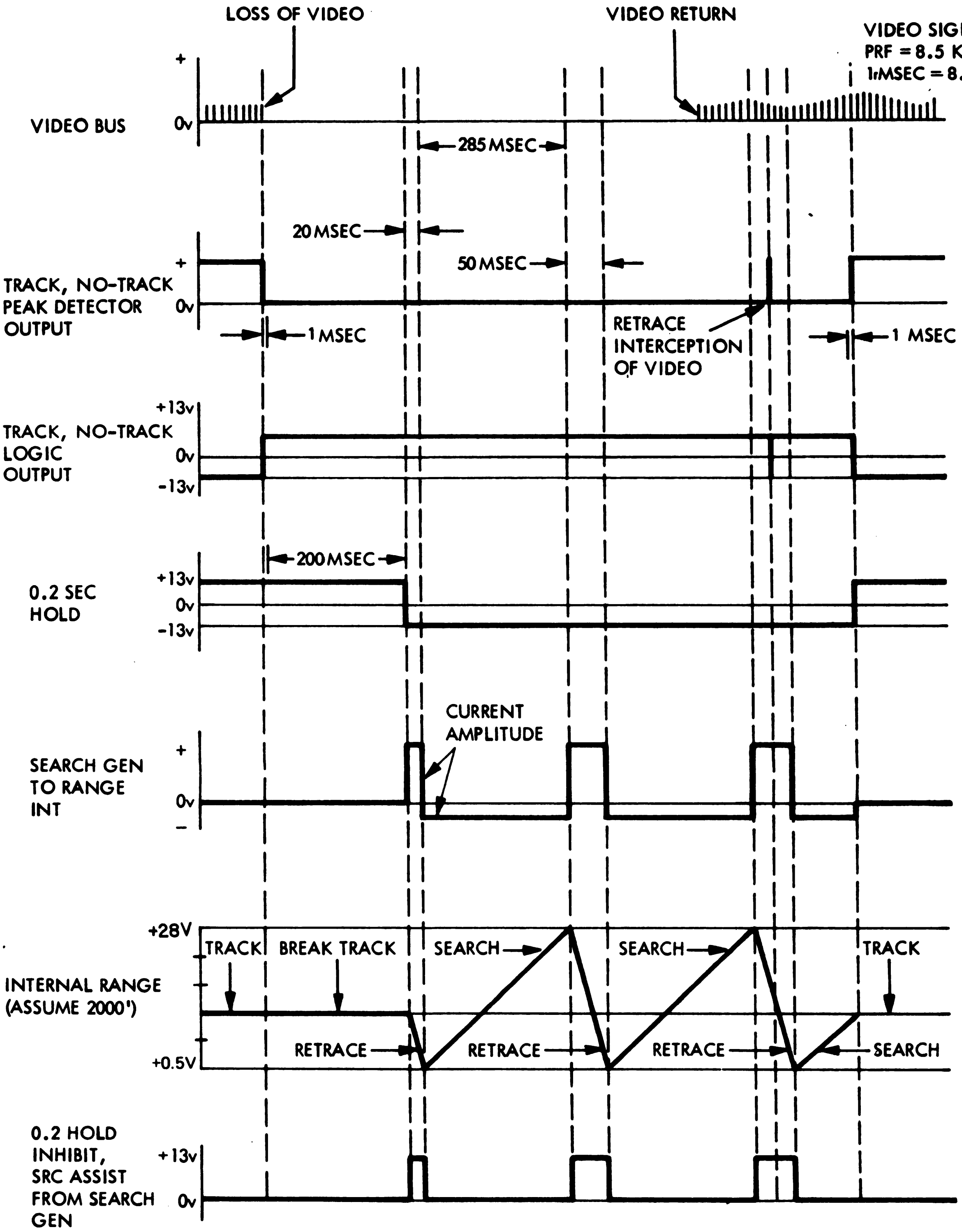

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Figure 2-41.—Search and acquisition waveforms.

waveform relationships. When video return pulses of adequate amplitude return, the kagc gate pulses will overlap them. After successfully sampling several video pulses, the command to the track/search control causes it to remove all its overriding controls, enabling the normal track mode of operation.

Altimeter Transmitter

The altimeter transmitter module contains the circuitry necessary to generate and control the RF energy pulse, which is supplied to the antenna system, and the circuits needed to detect that pulse and supply a corresponding time-zero pulse to the range computer. Basically the circuits are those of a typical radar transmitter, which was covered in Chapter 4 of *Avionics Technician 3 & 2,* Part 1.

Altimeter Receiver

The altimeter receiver module contains the circuits necessary to produce a usable video signal for the range computer. It is typical of most superheterodyne receivers.

Altimeter Height Indicator

The height indicator is both the control box and height readout for the radar altimeter system. Figure 2-42 shows the front view of a typical altimeter height indicator. It is a null-balancing servo device, which operates from the radar range voltage (analog signal) from the R-T range computer, and a reference voltage also supplied by the R-T unit's power supply. The indicator also contains a low altitude warning circuit which is energized whenever the height indicating needle reads lower than the altitude selected on the low altitude limit index. The warning circuit will illuminate the low altitude warning light. In some indicators, a 400-cycle tone to the headset is also supplied in the event of low altitude.

Transmitting and Receiving Antennas

The transmitting and receiving antennas are identical. They are flush mounted, dielectric-loaded, flared-horn type antennas. (See figure 2-43.) Operation is in the 4,250- to 4,350-megacycle range (typical frequency range of radar altimeters).

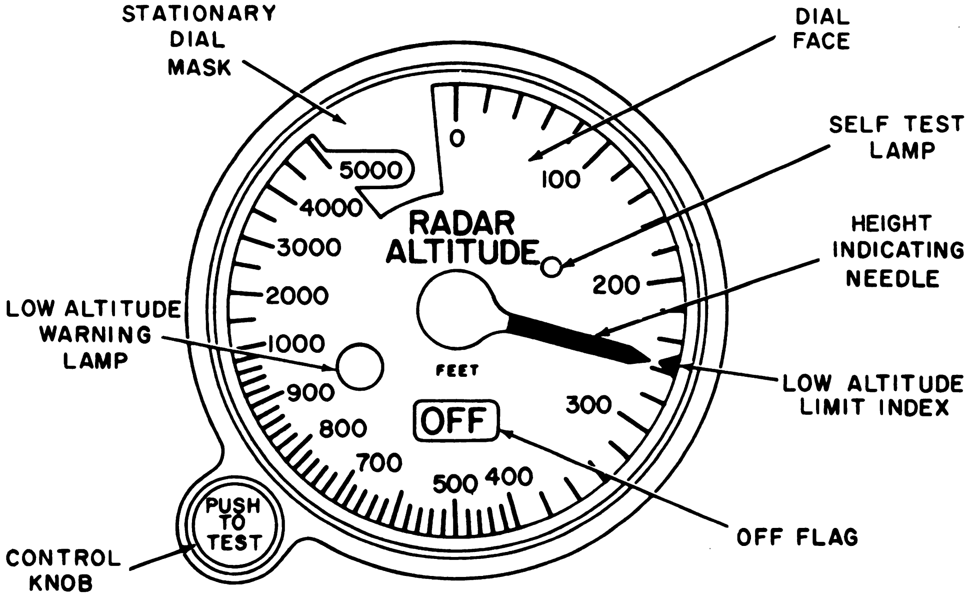

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Figure 2-42.—Front view of typical radar altimeter height indicator.

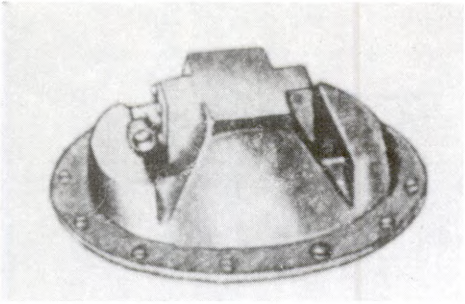

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Figure 2-43.—Typical radar altimeter flush mounted antenna.

Interference Blanker

An interference blanker is required by a radar altimeter system only if the receiving and transmitting antenna isolation is less than 85 db. It consists of RF attenuators, RF isolators and a pulse shaping network. Its sole purpose is to attenuate the RF signal resulting from direct antenna leakage, to a level that is below the tracking capability of the altimeter system. This prevents possible zero-altitude indication (zero-lock) above the altimeter's maximum altitude (5,000 feet for the APN-194).

SYSTEM OPERATION.—Refer to figure 2-42 during the following discussion. The control knob is the system's sole operating control. In the fully counterclockwise position (indented) the power is "off." Turning the control clockwise past the indent turns the system "on." After a short warm-up period, the "OFF" flag will disappear, indicating the system is on. Further adjusting of the control knob will adjust the low-altitude index needle. The altimeter should lock on 0-6 feet of altitude, depending on the particular aircraft.

Pushing in on the control knob initiates the "self-test" feature. Most self test circuits will cause the altimeter to read 100 feet. (This could vary.) With the indicator needle reading the self-test altitude, adjust the low altitude index to some altitude reading below it. The low altitude warning light should light and a low altitude warning signal (if supplied) should be heard in the headset.

Once the aircraft is airborne, the operator need only to turn the system "on" and adjust the low altitude index pointer to the desired low limit. The system will then automatically read out the aircraft's height above the terrain and will give a low warning indication any time the aircraft drops below the pre-set low altitude index needle. See figure 2-43 for a typical radar altimeter flush-mounted antenna.

LORAN

The word LORAN is formed from the words LOng RAnge Navigation. It is a navigational system developed primarily to provide a means for making geographical fixes by the use of long range radio signals. The system is a valuable aid to navigation, since loran fixes can be made quickly and accurately both by night and day. It is reliable for both air and surface navigation under most weather conditions. Often, loran signals can be received even during storms, except those involving severe electrical disturbances. The principal value of loran lies in its capability for continued operation during conditions which make celestial navigation difficult or impossible; for example, any situation in which the stars are not visible.

PRINCIPLES OF LORAN

Loran differs from radar because the airborne unit simply receives radio pulses broadcast from ground stations, and no reception of echo signals is involved. Additionally, the basic loran measurement is that of time difference of arriving signals with no regard to the direction from which they arrive; hence, the complicated directional antennas used in radar equipment are not necessary. Despite these differences, however, loran is closely related to radar since it uses pulse type equipment, and it employs radar techniques of time measurement. Also, visual displays of the signals received are made on cathode-ray tubes used as indicators.

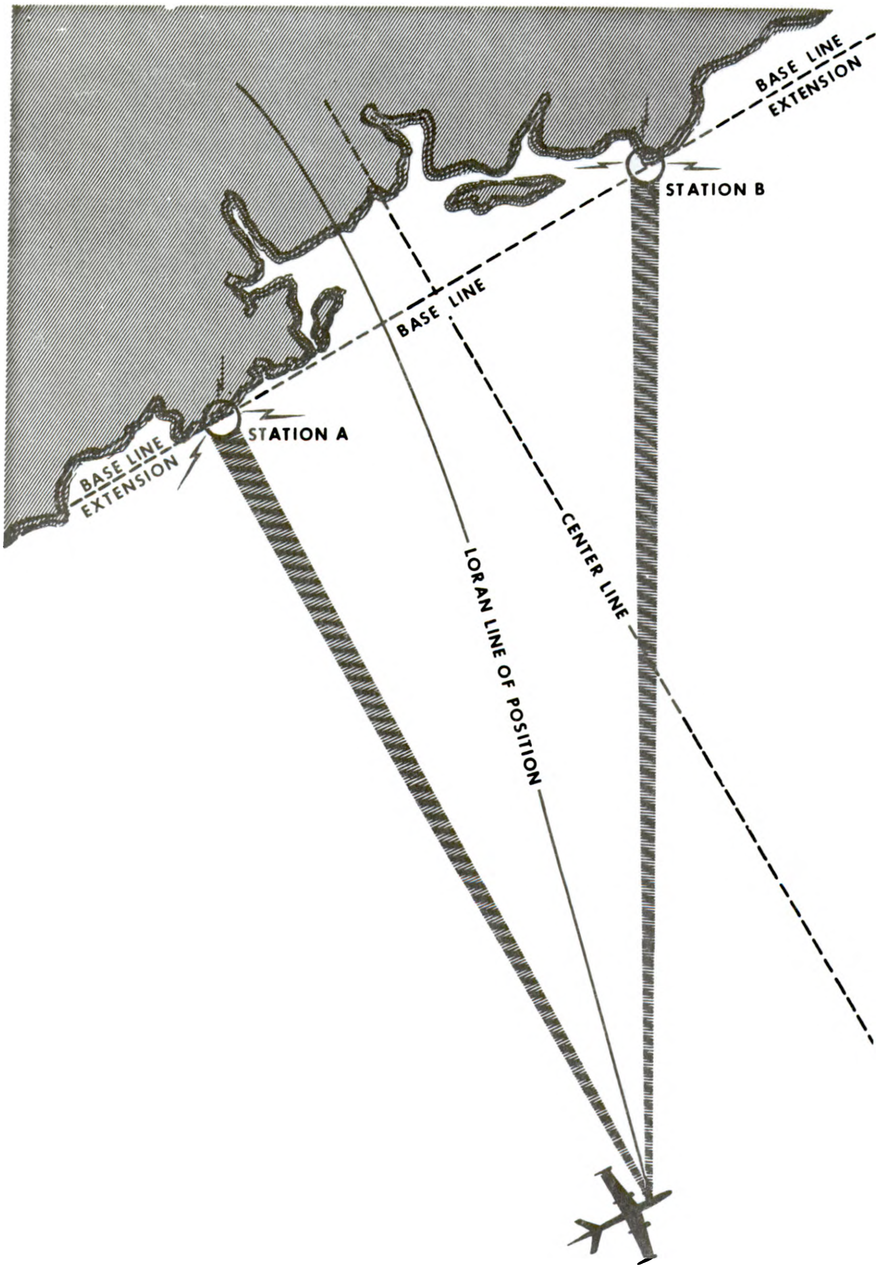

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Figure 2-44.—The principle of loran.

The basic principle of the system is illustrated in figure 2-44. Two stations are necessary to establish a loran line of position. The master station A emits a continuous series of uniformly spaced pulses at a stable pulse recurrence rate. The slave station B sends out a similar series of pulses which are synchronized with the master pulses. The master and slave stations are usually 500 to 700 miles apart. The line joining the two stations is called the baseline, and its perpendicular bisector is called the centerline. The baseline extension is a straight line drawn beyond either station as a continuation of the baseline.

Assume that the two stations are sending out pulses simultaneously; then at any point along the centerline, the two signals arrive at the same instant (since all points of the line are equidistant from the two transmitters). If an observer is located nearer station A than station B, the A pulse arrives at the observer's position first, followed (after a measurable time interval) by the corresponding B pulse. By moving to different positions located in the same vicinity, the observer could record the time interval (difference in arrival time of the A and B pulses) corresponding to each position. If several positions having the same time interval were joined by a smooth curve, the curve thus traced would be a line of position for station pair A and B.

Since RF energy travels at a constant velocity, the difference in the time of arrival of the pulses corresponds to the difference in distance from the stations, and can be accurately calculated and plotted on a chart. Selected line of position curves may be drawn by connecting points of equal computed time or distance values. Each curve so constructed has the shape of a hyperbola, which is the mathematical name for a curve consisting of points whose difference in distance from two fixed points (in this case, A and B) remains constant. Thus, loran is called a hyperbolic system of navigation.

A large number of lines of position are drawn for each pair of transmitters as shown in figure 2-45. Each line is labeled with a number indicating the time interval in microseconds between the arrival of the corresponding loran pulses.

In (A) of figure 2-45, zero time difference exists along the centerline, while maximum time difference exists along the baseline extensions. Lines with equal time difference may be noted on each side of the centerline, since there is no way to determine which pulse is received from which station. In actual practice, however, the signals are not emitted simultaneously. The slave station pulse is delayed so that, at any point, the master station pulse is received before the corresponding slave pulse. As a result, each curve of the family has a discrete time interval value as indicated in (B).

The delay of the slave pulse includes several increments. The master station transmits a pulse to initiate the sequence of events. An interval of time elapses during which the signal reaches the

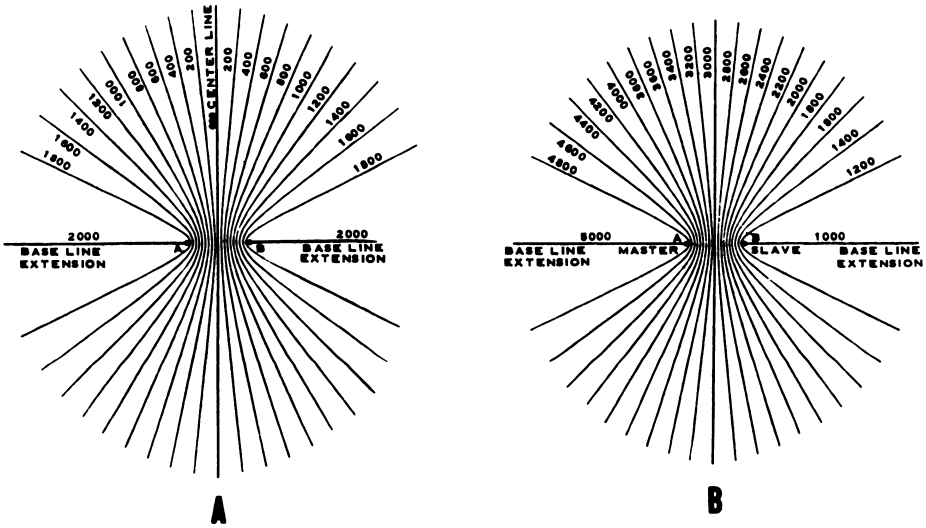

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Figure 2-45.—Lines of position. (A) No time delay; (B) 3,000-microsecond delay.

slave station. The slave station receives the impulses and waits an initial period of time (equal to one-half the pulse recurrence interval) plus an additional period of time (called the coding delay). It then emits a pulse. The sum of the travel time, half the recurrence interval, and the coding delay is called the absolute delay. As a result of the delay, the master pulse always precedes the slave signal at any point of reception. The difference in arrival time is maximum along the baseline extension beyond the master station and minimum on the baseline extension beyond the slave station.

LORAN NAVIGATION

The loran navigation network was designed to cover a vast ocean area. This coverage, coupled with the long distance usage, requires a large number of ground transmitting stations. Due to frequency restrictions because loran operates in a crowded portion of the frequency spectrum, only a few specific frequencies were set aside for the stations. To make possible station identification, with few frequencies available for differentiation, each station utilizes a different pulse repetition rate (PRR). The airborne receiver can thus distinguish between various pulse pairs and measure the time interval for any selected pair by selecting (tuning the receiver) a particular PRR. Other pulses of the same frequency are not synchronized with the receiver's scope sweep time (due to the receiver's PRR setting), and therefore would drift across the screen.

In order to determine a position by loran, it is necessary to obtain intersecting lines of position from two or more station pairs, then refer to a special loran chart to locate the position of that intersection.

The U.S. Navy Hydrographic Office publishes loran charts (which are standard Mercator charts with loran lines of position superimposed). The use of the chart in obtaining a "fix" is illustrated in figure 2-46.

A loran chart shows the lines of position of one station pair crossing those of another. In many installations, the two pairs consist of a single master station operating in conjunction with two slave stations. This is called double-pulsed transmission and is the type represented in figure 2-46. The common master station emits two sets of pulses. Each set is synchronized with one of the adjacent slave stations. In the figure, the master station is labeled P, and the slave stations are labeled R and Q. The combination P-R operates with a pulse recurrence rate that is different from the combination P-Q. Two families of lines are available, and the fix is made by taking measurements on both pairs, locating the observer at point X.

When loran fixes are made, the general location is usually known. The navigator consults the loran chart for that particular area and selects a station pair by setting the receiver controls according to the symbols given on the chart. The principal receiver settings are for channel frequency, basic pulse recurrence rate (high or low), and specific pulse recurrence rate. These required settings are indicated by the letter-number groups noted on each line of position. The last part of the group is the time difference (in microseconds) for that line of position.

The loran system used to be comprised of two subsystems which differed in mode of operation. There was a basic loran "A" system with a transmitting configuration consisting of a single slave station operating in synchronous sequence with a master transmitting station, designated a pair, and each having a common RF frequency and PRR (shown in figure 2-46). In order to obtain a fix from two lines-of-position, separate measurements had to be made from two pairs of stations. The second subsystem, designated loran "C," is more complex, but provides better accuracy at greater distances.

The loran A system has been shut down and only the loran C system is still used.

LORAN C

The loran C system is similar to loran A in that each station has a master station working in synchronization with slave stations. The loran C station utilizes two or more slave stations vice just one for loran A, and all loran C stations operate on one transmitting frequency of 100 kHz, with the slave stations of a particular master station operating at the same PRR as the master station. This allows an operator to read the time delay (arrival time) on two station pairs

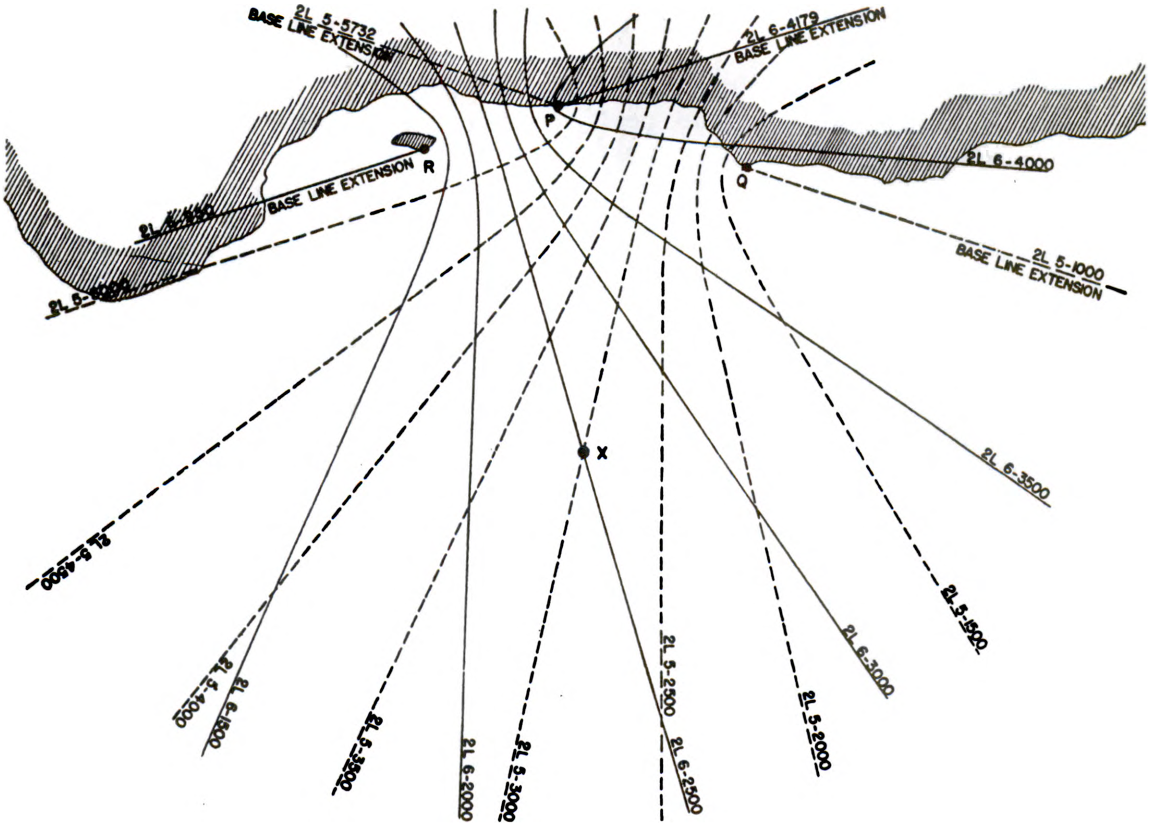

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Figure 2-46.—Obtaining a loran fix.

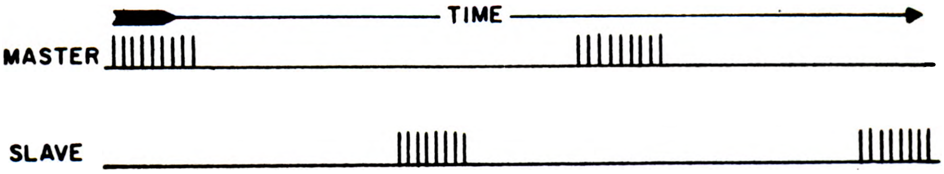

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Figure 2-47.—Loran C pulse groups.

(master and its slaves) without receiver tuning. The loran C master station's pulse group consists of nine pulses spaced either 500 or 1,000 microseconds apart, except for the ninth pulse which is separated from the eighth pulse by 600 microseconds. The slave station's pulse group transmission is a group of eight pulses with the same 500 or 1,000 μsec spacing as the master. Loran C pulse groups are illustrated in figure 2-47.

Loran C has six basic PRRs that are divided into two groups; single rate, and double rate. The single rate has three basic PRRs, 33-1/3, 25, and 20 Hz, that are designated H, L, and S, respectively. These rates produce pulse recurrence intervals of 30,000 microseconds for the H rate, 40,000 microseconds for the L rate, and 50,000 microseconds for the S rate, varying slightly for specific PRRs.

The double rate is one-half the single rate, and has 16-2/3, 12-1/2, and 10 pulse groups per second, (designated SH, SL, and SS, respectively). These rates produce pulse recurrence intervals of 60,000 microseconds for the SH, 80,000 microseconds for the SL, and 100,000 microseconds for the SS. Notice that these rates result in intervals double that of a single rate.

A typical loran C transmitter arrangement is the star chain shown in figure 2-48. In this configuration, four stations, a master (designated M) and three slaves (designated X, Y, and Z) transmit pulse groups. The transmissions of the slave stations are timed with respect to the master station to establish an accurate basis for the time measurements.

The master station starts the action by transmitting a pulse group of nine pulses. The pulse group transmission is received by the X, Y, and Z slave stations. After a predetermined delay, the X station transmits its pulse group. After a somewhat longer predetermined delay, the Y station transmits, and after another delay, the Z station transmits. These delays permit the signals to arrive at the loran C receiver in the M, X, Y, and Z sequence anywhere in the service area.

The results of these transmissions are three sets of lines of position (lop's), one set of each combination of master and slave. By measuring the difference in arrival time of the signals from the three slaves and the master, three lines of position may be located on the loran C chart. The intersection of the three lines of position produces a loran C fix. (NOTE: All the signals are received by the airborne receiver since the frequency and PRR of all four stations are the same. Only the start time of transmission is different.) Signals from the loran transmitter reach the airborne receiver by ground wave, by a sky wave reflected from one of the atmospheric layers of the earth, or by a combination of the two. Ground waves are normally much more accurate than sky waves. Figure 2-49 illustrates the type of signal reception that can be expected during loran navigation.

Within 500 miles of a transmitting station, with the transmission path completely over water, ground waves are expected as the first pulse to arrive, followed by a one-hop-E sky wave, then the two-hop-E sky wave and so on. Beyond 800 miles the first pulse to be received

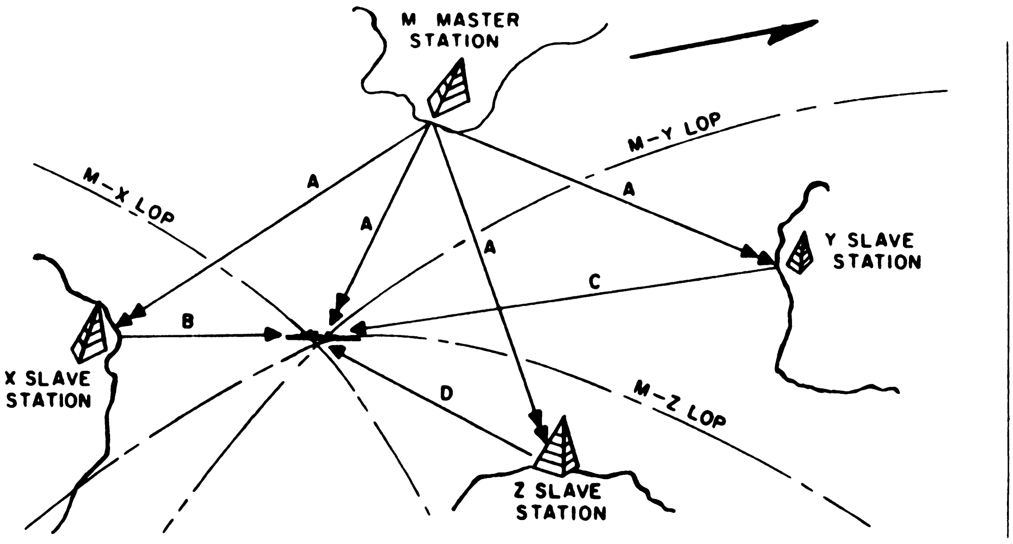

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Figure 2-48.—Loran C star chain transmitter arrangement.

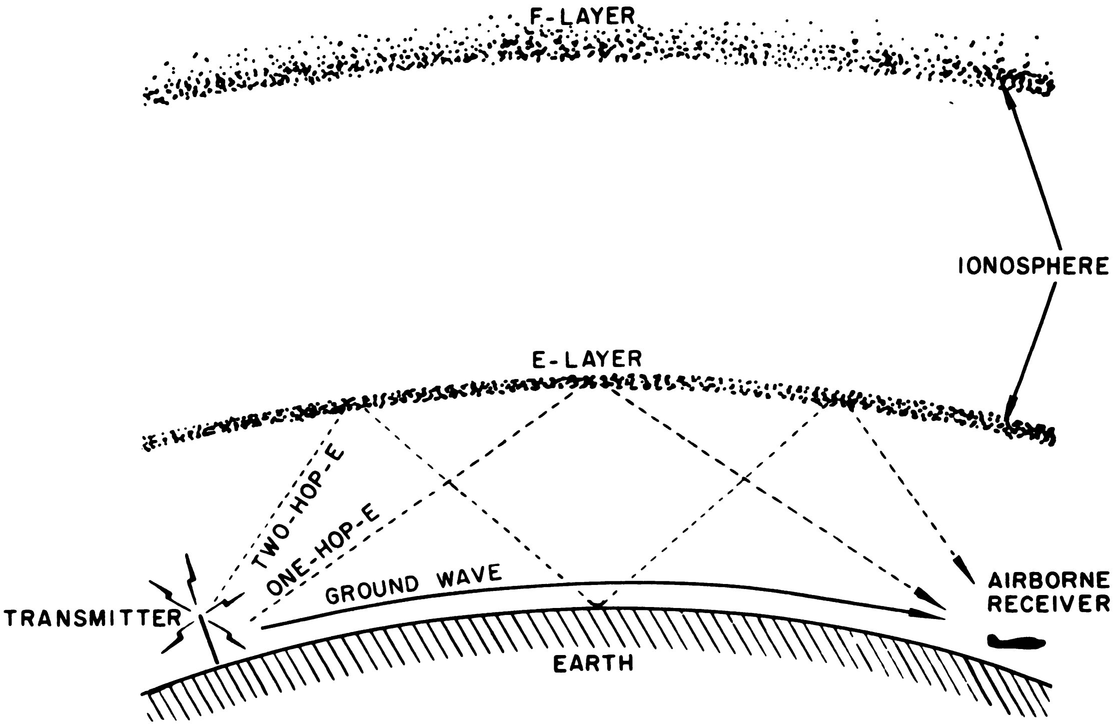

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Figure 2-49.—Ground aud sky wave signals.

will normally be the one-hop-E sky wave, as it overpowers the ground wave signal. At distances over 1,100 miles, the two-hop-E sky wave will begin to overpower the one-hop-E sky wave much the same as the one-hop-E sky wave overcame the ground wave at 800 miles.

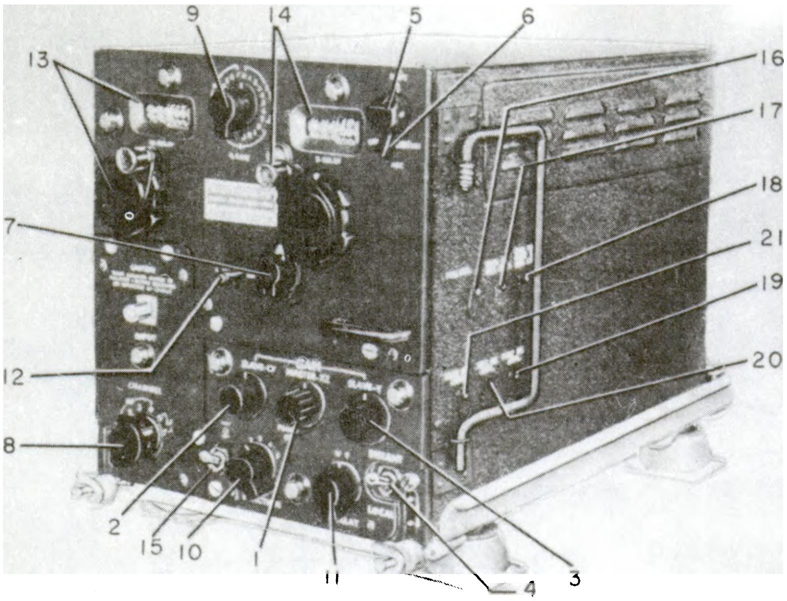
As previously stated, data defining the master-slave time difference is presented as hyperbolic lines of position on air/surface loran Mercator charts (maps), along with station information. The combination of numbers and letters in the designation of a loran line on a loran C chart indicates the basic PRR, specific PRR, station type designation and the time difference in μsec. The constant time difference presented is for ground wave data. To compensate for the longer transmission path for sky wave signals, sky wave correction factors are shown in μsec's at latitude-longitude grid intervals on the loran charts. This correction factor is added or subtracted from the receiver's digital readout to obtain the corrected time difference.

How the operator determines whether the receiver is displaying a ground wave or a sky wave will be discussed later in this chapter.

LORAN AIRBORNE RECEIVING EQUIPMENT DL-70A/C

The DL-70A/C loran set was originally designed for both loran A and loran C navigation. We will only discuss the loran C functions, as loran A has been discontinued. Although there are newer loran C equipments, the operating concepts are the same and will give you the fundamentals of loran C navigation. Figure 2-50 shows the DLR-70A/C receiver with its operating controls, and figure 2-51 is an illustration of the DLI-70A/C indicator used with the receiver. The receiver unit contains all the controls necessary to operate the system, and the indicator displays the signals of the receiver.

For explanation purposes, we will only discuss the W channel of operation. (The Y channel operates in exactly the same manner.) Refer to figure 2-50 during the following discussion.



Index No.	Nomenclature	Function
1	MASTER-XZ	(A) ON-OFF power control (B) Master gain control (master pulse level)
2	SLAVE-W	Slave gain control (slave pulse level)
3	SLAVE-Y	Slave gain control (slave pulse level)
4	LOCAL-DISTANT	Receiver sensitivity range
5	DRIFT	Synchronize receiving set with loran transmitting group
6	AUTOMATIC DRIFT CONTROL (ADC)	Automatic R-rate synchronization
7	MODE SELECTOR	"A," "C" or "Cs" selection (*1)
8	CHANNEL	Station selection
9	R-RATE	Station pulse repetition rate (see Table 2-4)
10	FUNCTION	Display mode selector
11	DELAY	Variable time delay selector (W or Y)
12	L-R SWITCH	Pulse train position control
13	W-DELAY (crank)	Vary Slave-Delay time
	W-DELAY (counter)	Slave-Delay time in microseconds
14	Y-DELAY (crank)	Vary Slave-Delay time
	Y-DELAY (counter)	Slave-Delay time in microseconds
15	COHERENT DETECTOR	Eliminate undesirable signals
16	PED. DUR.	Adjust pedestal width
17	SLOW SW. HOR. CENT.	Adjust horizontal centering in "Function 1"
18	MED. TO FAST SW. HOR. CENT.	Adjust horizontal centering in "Function" switch positions 2, 3, 4 and 5
19	FAST SW. AMPL.	Adjust sweep length in "Function" switch positions 3 and 5
20	MED. SW. AMPL.	Adjust sweep length in "Function" switch positions 2 and 4
21	SLOW SW. AMPL.	Adjust sweep length in "Function 1"

(*1) Mode "Cs" is the same as "C" except for longer rep. rates.

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Figure 2-50.—DLR-70 A/C Loran receiving set with operating controls and adjustments.

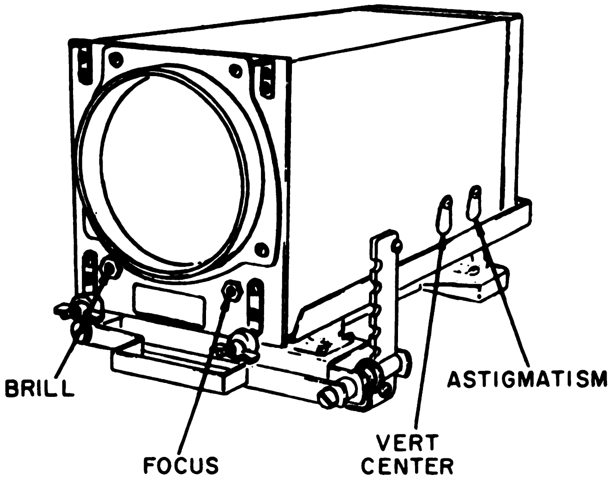

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Figure 2-51.—DLI-70 A/C indicator.

To receive loran C signals on the W-channel, the receiver controls are preset as shown on table 2-3. (See table 2-3 and table 2-4.)

With the system in function 1, but prior to receipt of loran C signals, one sweep with two pedestals (generated by the receiver) will appear on the indicator. (See figure 2-52A.) The position of the slave pedestal on the sweep is controlled by the W-delay crank (13), and the master pedestal will occur at the beginning of the sweep.

Once loran C signals (100 kHz) are received, the indicator will display the master and slave pulses of the stations transmitting at the PRR as selected on (9) R-Rate switch. (See figure 2-52B.)

By utilizing the L-R switch (12) the received pulses can be positioned anywhere along the

Table 2-3.—Loran C Initial Control Settings (NOTE: Index numbers correspond to fig. 2-50.)

INDEX NUMBER	NOMENCLATURE	POSITION
1	MASTER-XZ	TURN CLOCKWISE TO THE CENTER OF ITS RANGE
2	SLAVE-W	TO THE CENTER OF ITS RANGE
4	LOCAL-DISTANT	AS REQUIRED FOR SIGNAL STRENGTH
6	ADC	ON (AUTOMATIC DRIFT CONTROL)
7	MODE SELECTOR	C OR Cs (DEPENDING ON STATION PRR)
8	CHANNEL	7 (FOR LORAN C FUNCTION)
9	R-RATE	SET TO NUMBER CORRESPONDING TO STATION PRR—TABLE 2-4 LISTS THE VARIOUS PRR RATES
10	FUNCTION	FUNCTION 1
11	DELAY	W-POSITION
13	W-DELAY (CRANK) W-DELAY (COUNTER)	TO THE APPROXIMATE TIME INTERVAL OF THAT INDICATED ON LORAN CHART FOR THE DESIRED STATION

Table 2-4.—PRR designations (NOTE: Index numbers refer to R-Rate (A) settings. See fig. 2-50.)

Switch Index	Mode C	Mode Cs
	Internal Cycle Time & Repetition Rate (μsec)	Internal Cycle Time & Repetition Rate (μsec)
S0	50,000	100,000
S1	49,900	99,900
S2	49,800	99,800
S3	49,700	99,700
S4	49,600	99,600
S5	49,500	99,500
S6	49,400	99,400
S7	49,300	99,300
L0	40,000	80,000
L1	39,900	79,900
L2	39,800	79,800
L3	39,700	79,700
L4	39,600	79,600
L5	39,500	79,500
L6	39,400	79,400
L7	39,300	79,300
H0	30,000	60,000
H1	29,900	59,900
H2	29,800	59,800
H3	29,700	59,700
H4	29,600	59,600
H5	29,500	59,500
H6	29,400	59,400
H7	29,300	59,300

sweep. (NOTE: All received pulses move simultaneously, and pulse spacing remains the same.) Position the first (extreme left) received pulse, which is the master station, directly over the master receiver pedestal. (See figure 2-53A.) Note that the received pulse appears to spread out. This is due to the fact that the sweep speed of the indicator is faster during pedestal time. Turn the W-delay crank (13) and position the slave receiver pedestal under the first received slave pulse (2nd pulse from left). (See figure 2-53B.)

Turning the function switch (10) to 2 will present the expanded pulse presentation in figure 2-53C. By further turning the W-delay crank (13), align the lower trace signals under the upper trace signals.

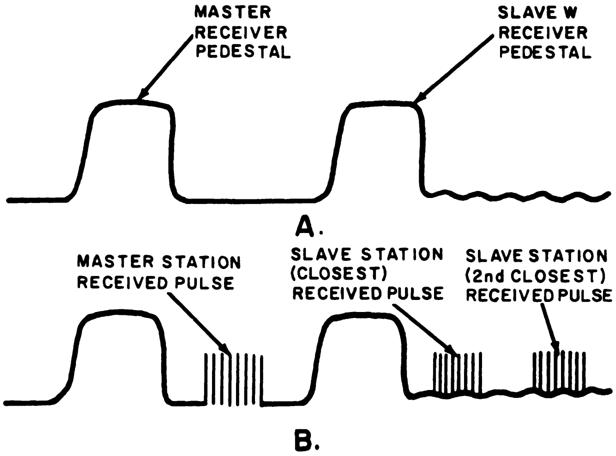
MASTER RECEIVER PEDESTAL
SLAVE W RECEIVER PEDESTAL
A.
MASTER STATION RECEIVED PULSE
SLAVE STATION (CLOSEST) RECEIVED PULSE
SLAVE STATION (2nd CLOSEST) RECEIVED PULSE
B.

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Figure 2-52.—DLI-70 A/C Indicator presentations on Function 1.

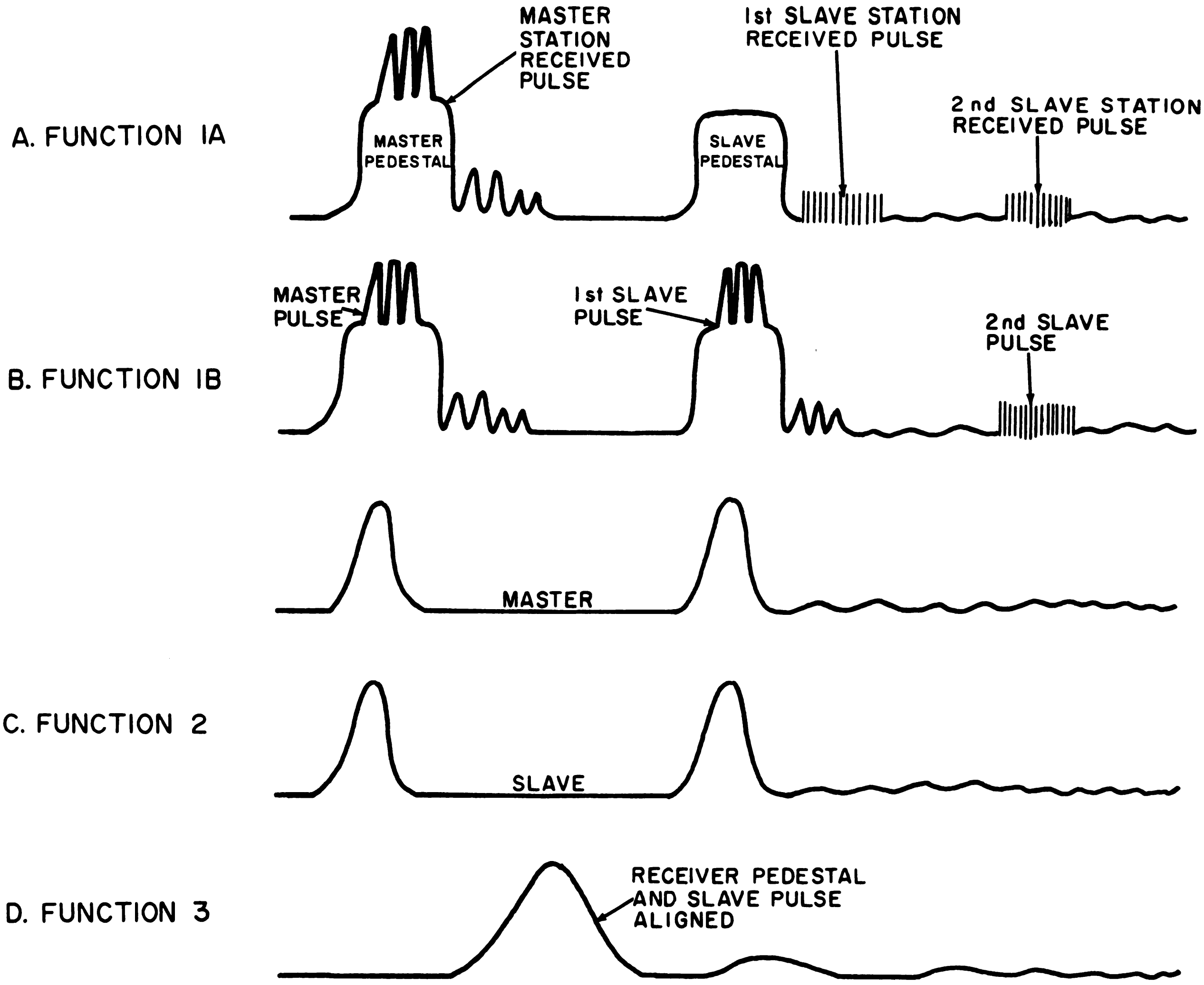

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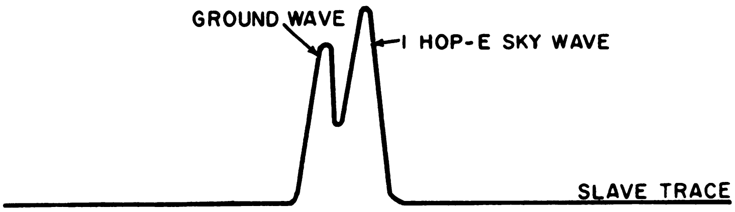
Figure 2-53.—Indicator presentations Functions 1 through 3.

Turn the function switch (10) to position 3. This function superimposes the two traces of function 2. Pulling out the W-delay crank will reduce the gear ratio. Fine tune the W-delay crank until the leading edges of the signals are aligned. (See figure 2-53D.)

The reading of the W-delay counter (13) is the time delay (arrival time difference) between reception of the master station pulse and the first slave station pulse. By consulting the loran chart, the closest reading on the chart which matches the W-delay counter reading is the LOP on which the aircraft is located.

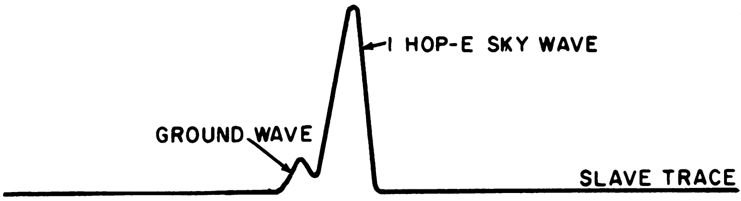
By selecting the Y-channel on the receiver and aligning the Y-slave pedestal with the 2nd received slave station pulse as above, you now have two LOPs which will give the aircraft's exact position on the loran chart (intersection of the two LOPs).

Under conditions of sky wave reception, multiple signals may appear on function 1. The operator should align the pedestals, etc., as previously described, as closely as possible.



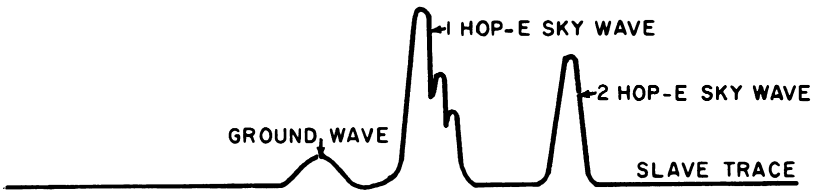
GROUND WAVE CLOSELY FOLLOWED BY STRONG SKY WAVE

A.



WEAK GROUND WAVE FOLLOWED BY STRONGER SKY WAVE

B.



GROUND WAVE FOLLOWED BY TWO STRONGER SKY WAVES

C.

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Figure 2-54.—Function 2 ground and key waves indicator presentation.

When function 2 is selected, multiple signals will also appear (see figure 2-54) on the bottom (slave) trace. By adjusting the master gain control to minimum (CCW) the operator should align the strongest pulse with the pedestal. If the sky wave is utilized, the proper sky wave correction factor on the loran chart must be added/subtracted from the W- or Y-delay counter reading to compute the actual time delay, prior to determining the nearest LOP.

Theory of Operation

The DLR-70 loran receiver unit is composed of three major units: the RF receiver, the timer, and the deflection units. These sections are shown in block diagram form in figure 2-55, which also includes the components of the loran indicator, and antenna system.

RF RECEIVER UNIT.—This portion of the loran receiver is a superheterodyne system, which contains an RF amplifier, a converter, two IF amplifiers, a detector, and a video amplifier. Loran signals are received from the antenna coupler by the RF amplifier, a tuned-grid, tuned-plate circuit. The output of the amplifier is applied to the converter stage.

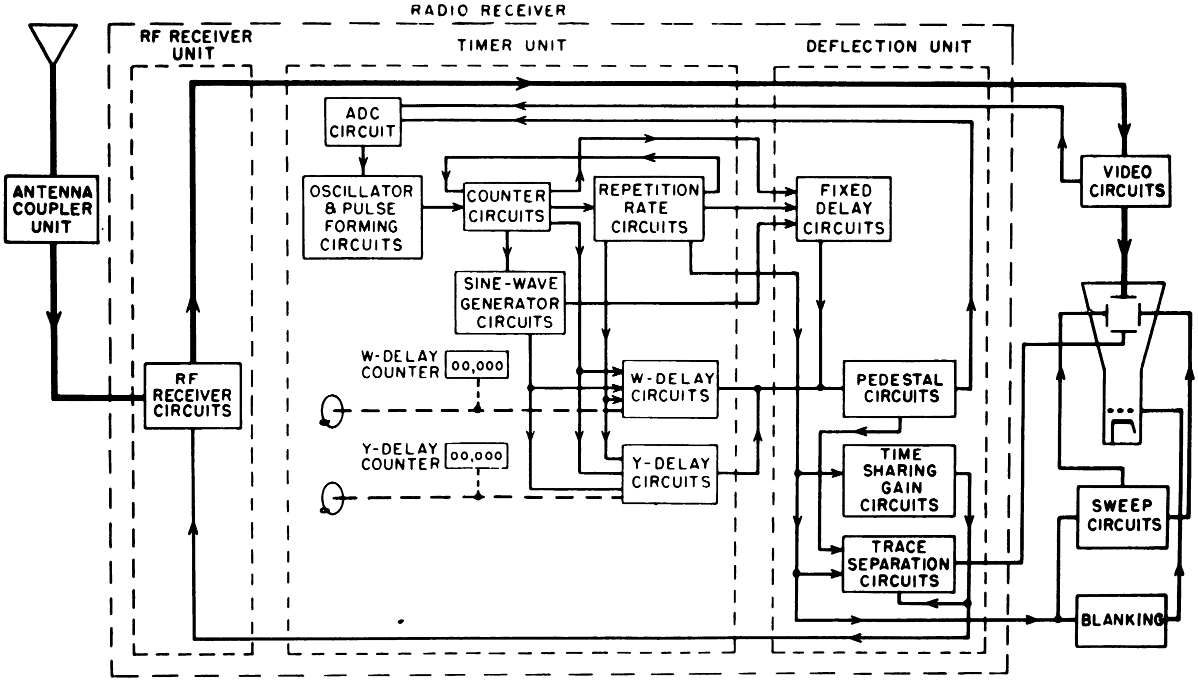

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Figure 2-55.—DLR-70 Loran receiving system simplified block diagram.

One section of the converter stage is used as a crystal oscillator circuit that produces mixing voltages. The IF output of the converter is amplified in the two IF amplifiers and fed to the detector. The resulting video pulses pass through one stage of amplification and are coupled through a cathode follower and the video section of the indicator to the vertical deflection system of the cathode-ray tube.

TIMER UNIT.—This unit generates a series of pulses serving as the time base of the equipment and produces the variable-delay intervals used to measure the time differences of the loran pulses. Also, to ensure that the receiving set and the transmitter system are operating at the same recurrence rate, the timer contains circuits for synchronizing the two.

The timing standard in the receiver is an 80-kHz crystal oscillator from which is derived (either directly or indirectly) the time bases for the timer, delay, and deflection circuits. The oscillator is synchronized with the time base of the loran transmitter by the action of the automatic drift control circuits. The oscillator can be changed in frequency over a narrow range by a reactance tube whose dc input grid voltage assumes a value corresponding to the degree of synchronism of the receiver circuits with the incoming loran pulses. The grid voltage of the reactance tube is produced by a discriminator tube which compares the repetition rate of the incoming master and slave pulses with the master and delay pulse pedestals from the receiver-indicator. (The master and delay pulses have a pulse rate set by the timer.) Any variation in the two rates produces a dc bias on the control grid of the reactance tube which, in turn, corrects the oscillator frequency and the resulting pulse rate derived from it. Thus, automatic drift control is established.

The sine-wave output of the crystal oscillator is shaped to produce a sharp negative driving pulse which is applied to the counter circuits. The electronic counter contains 12 identical multivibrators and 10 identical interstage amplifiers. Each counter stage is a binary counter (divides the input pulse rate by 2). The first 11 of these stages, together with 10 interstage amplifiers, are used to obtain the repetition rate. The 12th stage is driven by the output of the repetition rate circuits to obtain a square wave which is equal to the recurrence rate of the loran transmitting stations selected.

The first multivibrator of the counting series is triggered by 80-kHz pulses derived from the pulse forming circuits. The output of the first stage is fed to the grid of the first interstage amplifier tube which drives the second multivibrator. This sequence is repeated throughout the first 11 stages so that the overall division ratio is 2,048 to 1; hence, the counter chain gives one output pulse for every 2,048 pulses fed into it when all 11 counters are used.

The repetition rate circuits accept the output of the counter section and produce the reset pulses which determine the time at which the counter stages reach the count selected by the position of the recurrence rate switch. At that time a pulse is generated to reset the counter chain for the next cycle and to drive the 12th stage. The position of the recurrence rate switch may be set for any one of the 24 loran repetition rates. In addition, the repetition rate circuits supply trigger pulses to the fixed-delay circuits, the time-sharing gain circuits, and to the sweep circuits in the indicator unit on position 1 of the function switch.

The W- and Y-delay indicating systems consist of dials, switches, gear trains, gating tubes, wave shapers, pulse formers, and thyratrons. These systems are connected to stages 3 through 11 of the binary counter chain and to the 12th stage. Each delay system produces one output pulse during each L period. The occurrence of this output can be varied uniformly and continuously (after the second reset) to start the succeeding loran cycle by means of a handcrank. Two dials indicate the microseconds of delay produced at the thyratron of each system. The W and Y systems are identical in construction and operation except that their outputs appear in successive L/2 periods for operation with low-frequency loran signals (dual presentation). With high-frequency (single presentation) loran reception, only one delay system operates, as determined by the setting of the W-Y switch.

DEFLECTION UNIT.—In addition to the low voltage power supply, the deflection chassis contains circuits that receive signals from the timer unit. These signals are used to synchronize and trigger waveforms that perform the following functions:

1. Generate three independent bias voltages for the three time-sharing gain circuits

2. Generate waveforms to drive the sweep generator in positions 2, 3, 4, and 5 of the function switch

3. Generate trace-separation waveforms when required by the function selected at the control panel

In single presentation, the time-sharing gain controls enable the operator to adjust the receiver gain to an independent level on each trace appearing on the indicator screen. Either the W- or the Y-delay system may be independently selected by a control switch. In dual presentation, the delay reading and the gain setting of one pair of loran stations may remain on one counter dial and gain control knob while the operator is matching a second pair of loran pulses using the second delay system. The output of the time-sharing gain circuits supplies bias to the RF and IF stages of the RF receiver unit.

The trace-separation circuits are connected to the lower vertical deflection plate of the cathode-ray tube. The fixed-delay circuits provide a 1,625-microsecond delay for the trigger, governing the appearance of the master pedestal. For dual presentation, one trigger signal for every L/2 interval is provided; in single presentation, only one trigger signal for every alternate L/2 is required.

The pedestal circuits receive pulses from the fixed-delay and variable-delay circuits and generate waveforms to produce the master and slave pedestals. The output waveforms are supplied by a cathode-coupled, one-shot multivibrator which provides a pedestal of approximately 400 microseconds in positions 3 and 5 of the function switch in single and dual operation. The pedestal is 1,200 microseconds long in positions 1, 2, and 4 of the function switch in single operation, or 1,750 microseconds long in dual operation. In position 1 of the function switch, the multivibrator generates the pedestals seen on the traces on the indicator tube. In other positions of the switch, the pedestals are used to generate the traces, and only the video signals present during the portion of the pedestal covered by the trace are shown on the indicator tube.

LORAN INDICATOR.—As shown in figure 2-55, the loran indicator contains the sweep circuits for developing the horizontal deflection voltages, the cathode-ray tube blanking circuits, the video circuits, and the cathode-ray tube. In addition, the assembly contains two high voltage rectifiers which supply dc potentials for the CRT.

The sweep and blanking circuits are triggered by the reset pulses from the repetition rate circuits on function 1, and by the pedestal generator circuits on functions 2, 3, 4, and 5. A horizontal sweep generator supplies a sawtooth voltage waveform that is applied to the left horizontal deflection plate of the CRT. A portion of the output is also fed to a phase inverter stage to give an output wave 180° out of phase with the sweep generator output and which is applied to the right deflection plate, thus providing a push-pull horizontal deflection.

The blanking circuit extinguishes the electron beam in the indicator tube during retrace intervals in which the grid in the indicator tube is driven highly negative with respect to the cathode. A dc restorer diode clamps positive swings of the CRT grid to the voltage set by the brilliance control and establishes the level about which blanking takes place. An RC combination in the blanking circuit ensures that the traces seen on the screen of the indicator tube are delayed until after the start of the sweep to remove irregularities in the initial parts of the sweep cycle.

Video signals derived from the RF receiver unit are amplified in the video circuits and are applied to the upper vertical deflection plate of the CRT.

The dc voltages needed for operation of the CRT are supplied by low voltage regulator power supplies in the receiver unit, and by the two high voltage rectifiers in the indicator assembly. One high voltage rectifier produces a dc potential of 1,300 volts, positive with respect to ground, which is applied to the indicator tube through a cap connection. The other high voltage supply develops 1,300 volts, negative with respect to ground, and is applied to the cathode of the tube.

OMEGA NAVIGATION SYSTEM

The Omega navigation system is an outgrowth of the loran A, and loran C systems. It is a worldwide network of seven (soon to be eight) transmitting stations, which produce very low frequency signals to provide LOPs over the globe, with accuracy to within four nautical miles. The seven operational stations are located in Hawaii, North Dakota, Norway, Argentina, Liberia, La Reunion (off the coast of Madagascar), and Japan. An eighth station in Australia is expected soon.

OMEGA PRINCIPLES OF OPERATION

The Omega system relies on the characteristics of radio wave propagation, and specifically on the characteristics of radio waves in the very low frequency (VLF) range.

In general, a given phase position of a radio wave (sine wave) occurs periodically (in time) as each 360 degrees of the cycle is repeated; thus, any phase angle will recur at various predictable intervals of a wave duration. The rate of recurrence, expressed in time, is dependent upon the radio wave frequency. For

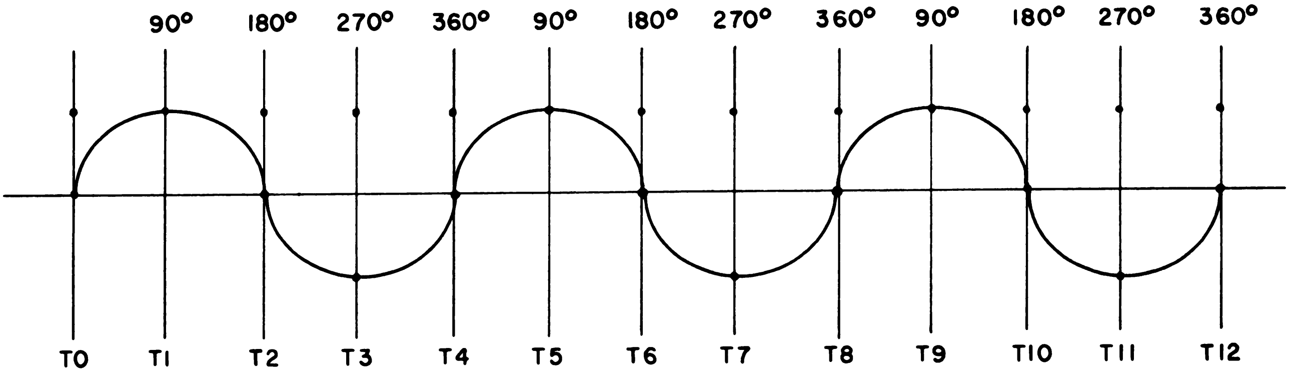

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Figure 2-56.—Phase/Time recurrence relationships of a radio wave.

example, note that in figure 2-56 the 90° signal phase position recurs at time T1, T5, and T9. If the frequency of the signal were 60 Hz, then 60 cycles would occur in 1 second. This means that each T (time) interval is equal to 1/60th of a second. Therefore, the 90° phase position occurs every 4/60th of a second after T1. Also, since radio waves travel at a constant speed, (6.18 microseconds per nautical mile) each T interval also represents distance, dependent on the wavelength of one cycle. This latter phenomenon furnishes the basis for a hyperbolic system similar to that of loran. The Omega system, however, differs from the loran system, in that the measurement of phase relationships between station signals, rather than time of reception, is utilized to determine a line of position (LOP). The system also employs cesium-beam oscillators to set the frequency standards and precise timing for each site, so that each of the seven stations is effectively a master station and may be paired with one or more other stations to obtain a position fix.

The time of the system is referred to as Omega time. By locking Omega stations to an absolute time standard, phase is, in theory, maintained stationary throughout the transmitter's field of radiation (i.e., earth's surface). This constant phase over the earth's surface may be translated into hyperbolic lines. The lines for any two Omega stations produce a family of hyperbolas called isophase (constant phase) contours. Each contour represents a line of zero difference in phase angle between the paired station signals. Since zero phase difference between signals will occur every 180°, or half wavelength, measured differences within these "lanes" will be unique to a specific distance from either zero-phase contour line (fig. 2-57). This relationship will be constant along the length of any zero-phase delineated lane; therefore, a line-of-position within a lane may be established by measuring phase angle difference between paired stations.

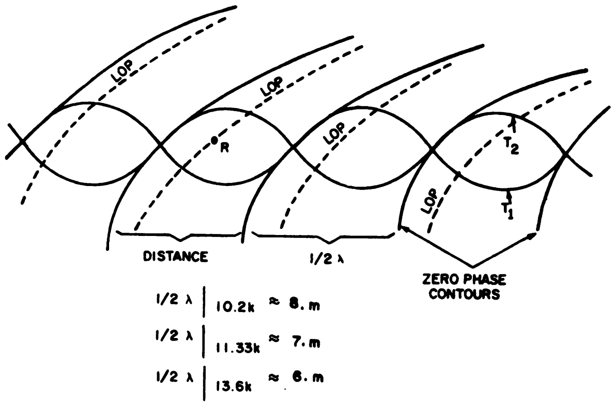

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Figure 2-57.—Zero phase contours.

Lane widths are determined by the frequency of transmission (fig. 2-58). The presently employed frequencies of 10.2 kHz, 11.33 kHz,

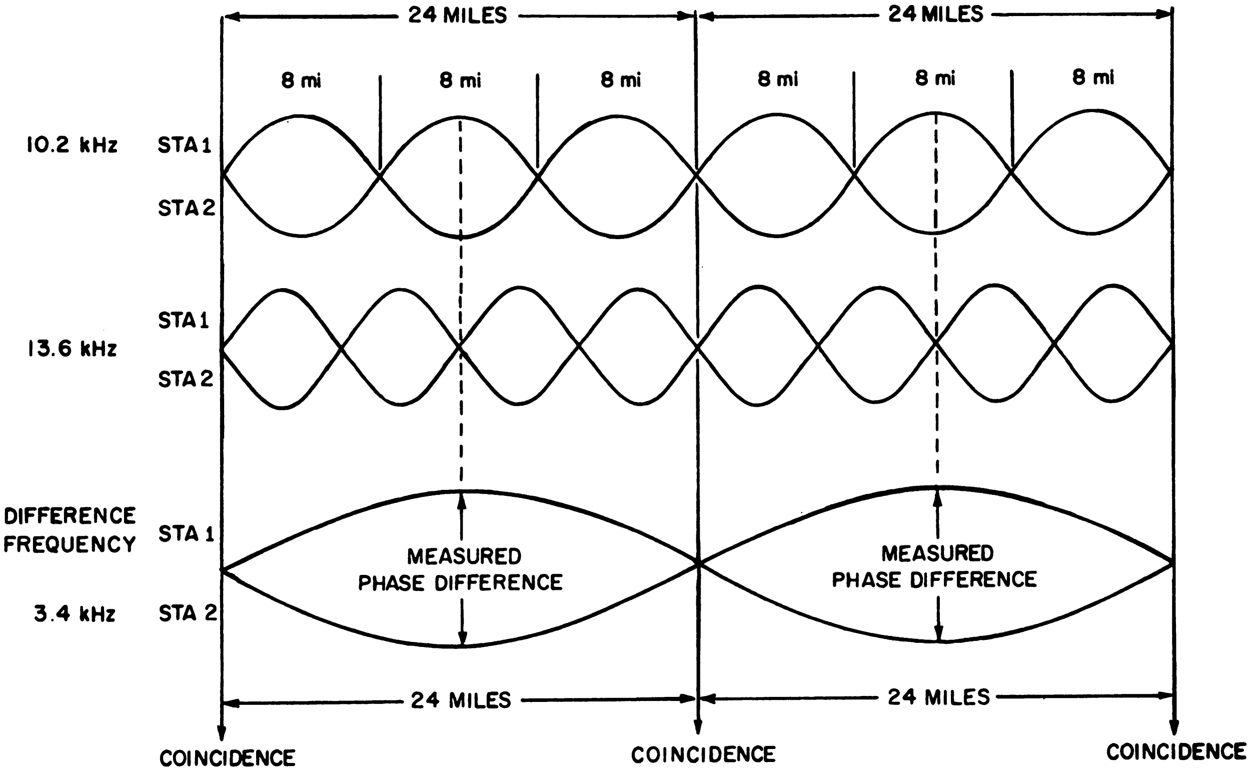

Figure 2-58.—Resolving lane ambiguity.

and 13.6 kHz have half wavelengths (distance between contours) of 8, 7 and 6 nautical miles respectively, along the baseline. Additionally, lane boundaries of 24 and 72 nautical miles may be derived by utilizing the ratios of the difference between 10.2 kHz and the other two frequencies. These broad 24- and 72-mile lanes may be used to resolve uncertainty in lane location.

Since the measured difference in phase angle can only produce a line of position within a known lane, it is essential to know in which lane the receiving station is located. This information is usually provided by counters or a graphic readout, associated with the receiver, which will count the number of lanes crossed. Lane identity, however, can also be resolved by taking advantage of the difference ratio in transmission frequencies in conjunction with another means of navigation, such as dead reckoning, celestial navigation or another electronic system. For example, when position is known to be within a broad 24-mile lane (dead reckoning to within ±12 miles), ambiguity between 8-mile lanes may be resolved by comparing the 10.2 kHz and 13.6 kHz frequencies. By adjusting phase synchronization so that a contour of the higher frequency coincides with a contour of a lower frequency, the difference ratio of 1/3 ($13.6 - 10.2/10.2 = 1/3$) will result in every fourth contour of the 13.6-kHz signal (fig. 2-58). A comparison of the two phase relationships will identify the 10.2-kHz lane in which the receiving station is located. A similar procedure may be used to resolve lane ambiguity within the broad 72-mile lane by employing the 11.3-kHz frequency.

A position fix is obtained by locating lines of position from additional pairs of transmitting

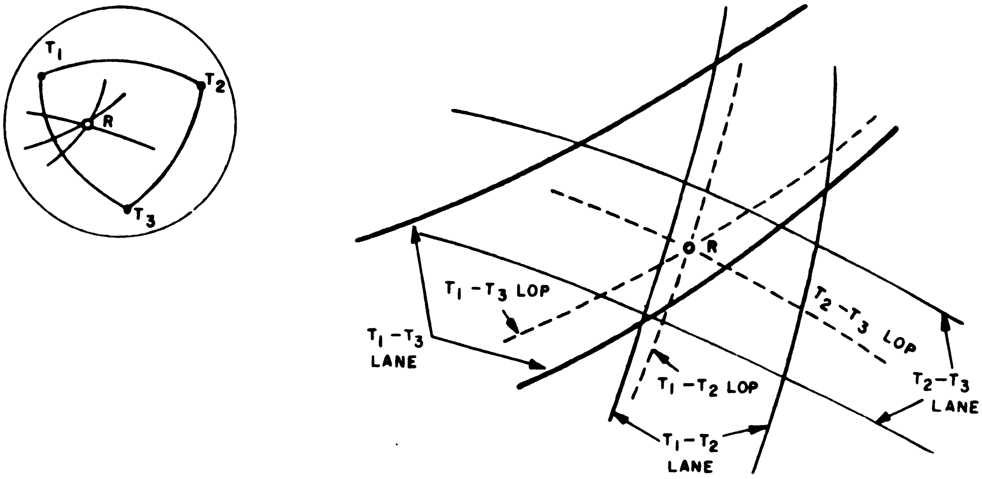

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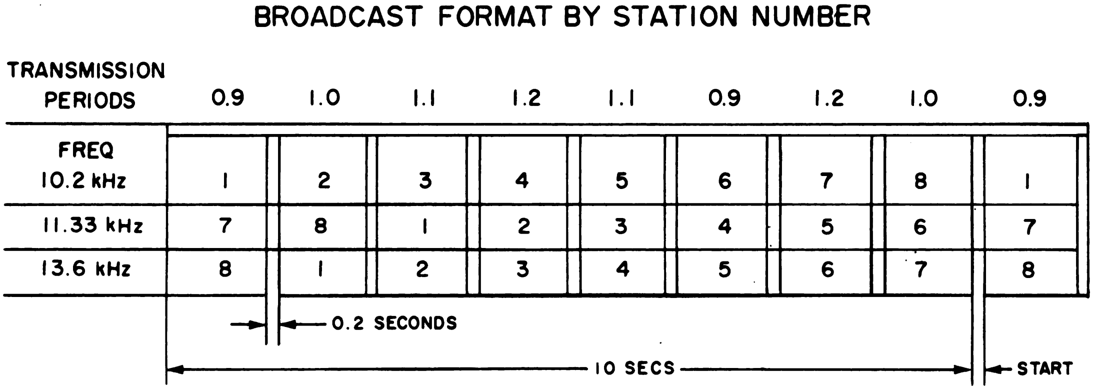
Figure 2-59.—Obtaining a position fix from three transmitting stations.


BROADCAST FORMAT BY STATION NUMBER

TRANSMISSION PERIODS	0.9	1.0	1.1	1.2	1.1	0.9	1.2	1.0	0.9
FREQ 10.2 kHz	1	2	3	4	5	6	7	8	1
11.33 kHz	7	8	1	2	3	4	5	6	7
13.6 kHz	8	1	2	3	4	5	6	7	8

0.2 SECONDS
10 SECS
START

245.46

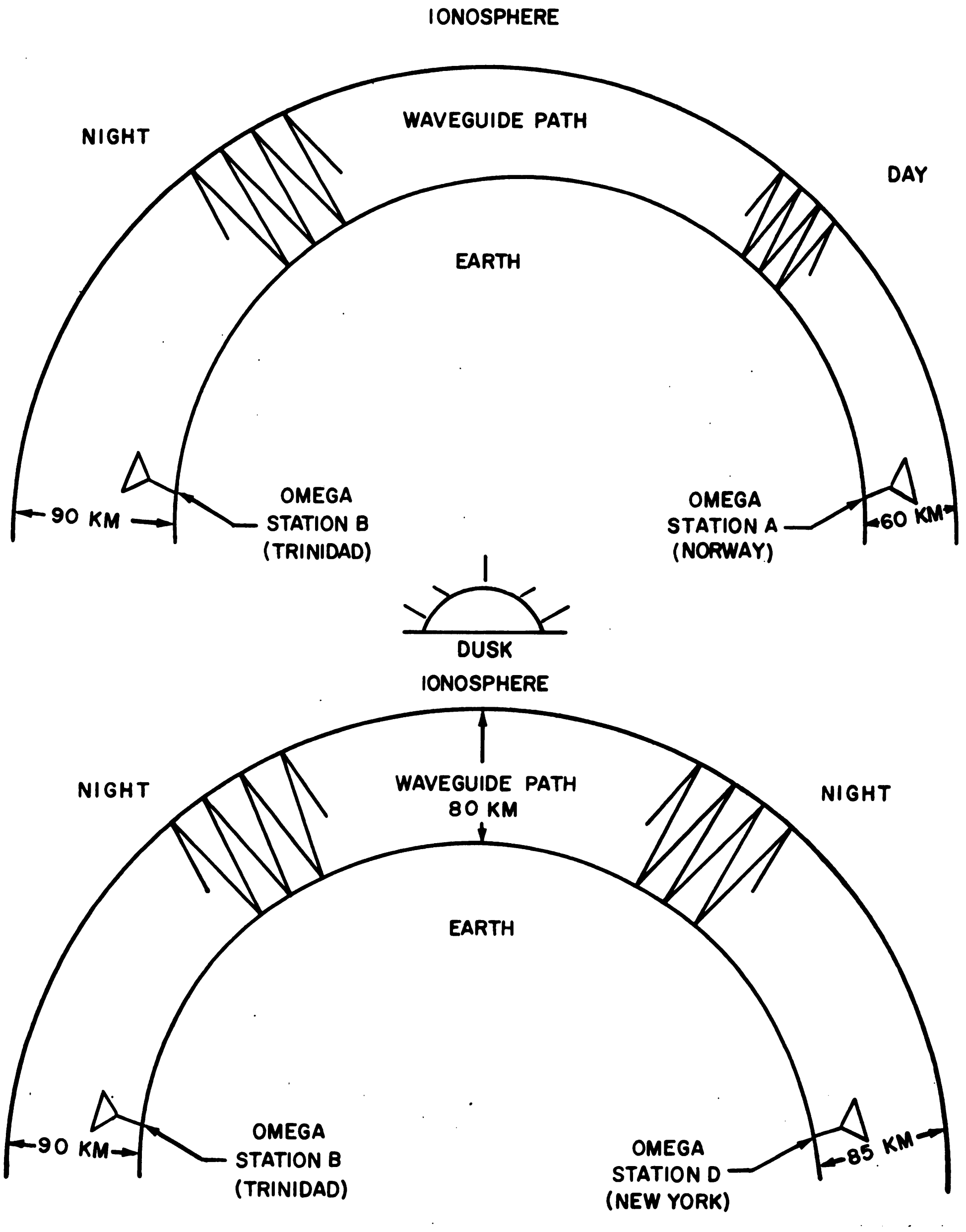
Figure 2-60.—Broadcast format.

stations. In figure 2-59, a position fix based on lines of position from three pairs of signals is shown.

Each station in the Omega system broadcasts a continuous-wave signal rather than a pulsed signal like that of loran. Because of the time separation between transmissions, the signal would have the appearance of being pulsed if seen on the cathode ray tube display of a receiver. This time separation is required, since each of the eight stations transmits on the same frequencies, and a means of identifying the sources of the signals being measured is needed. Examination of the broadcasting schedule of figure 2-60 shows a periodic pattern of interrupted transmissions repeating every 10 seconds. In this format, each station has a combined position/duration relationship that is unique. While stations 1 and 6, for example, are assigned the same signal duration on the 10.2-kHz frequency, their relative positions in the order of transmissions are different, and ambiguity is eliminated. Because Omega time is synchronized with, but is not identical to, Greenwich Mean Time, the identification of stations received during any 10-second cycle is possible by utilizing a time reference from another source such as the time signals broadcast by major naval radio stations.

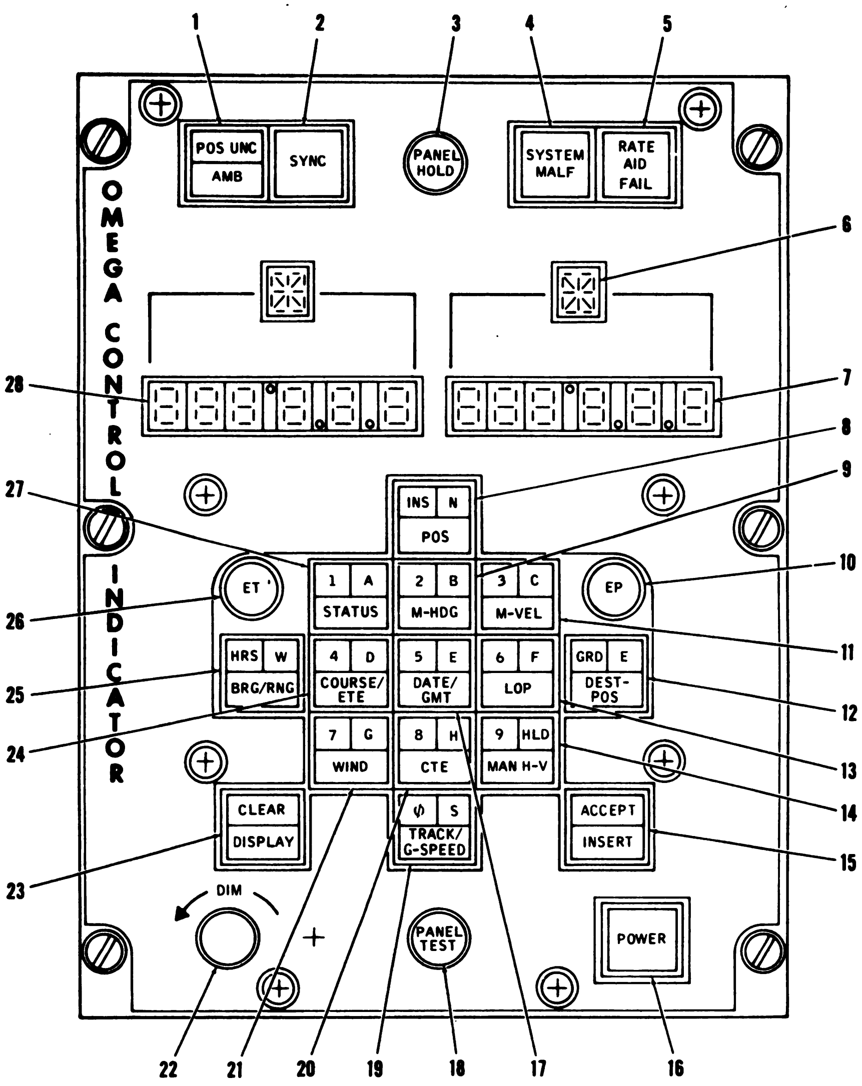
Omega Signal Propagation

The Omega system is essentially a skywave system, with the surface of the earth and the ionosphere forming a waveguide through which the transmitted signals travel (fig. 2-61). The ionosphere is a cloud of free electrons whose lowest region lies at altitudes of 40 to 50 miles above the earth's surface. Very low frequency signals, such as those of Omega, are refracted by the ionosphere and also reflected by the earth. The velocity of phase propagation will be determined



245.47

Figure 2-61.—Omega signal propagation.



1. POS UNC/AMB INDICATOR
2. SYNC INDICATOR
3. PANEL HOLD SWITCH-INDICATOR
4. SYSTEM MALF INDICATOR
5. RATE AID FAIL INDICATOR
6. ALPHA DISPLAY
7. RIGHT DIGITAL DISPLAY
8. INS/N/POS SWITCH-INDICATOR
9. 2/B/M-HDG SWITCH-INDICATOR
10. EP INDICATOR
11. 3/C/M-VEL SWITCH-INDICATOR
12. GRD/E/DEST-POS SWITCH-INDICATOR
13. 6/F/LOP SWITCH-INDICATOR
14. 9/HLD/MAN H-V SWITCH-INDICATOR
15. ACCEPT/INSERT SWITCH-INDICATOR
16. POWER SWITCH-INDICATOR
17. 5/E/DATE/GMT SWITCH-INDICATOR
18. PANEL TEST SWITCH-INDICATOR
19. φ/S/TRACK/G-SPEED SWITCH-INDICATOR
20. 8/H/CTE SWITCH-INDICATOR
21. 7/G/WIND SWITCH-INDICATOR
22. DIM POTENTIOMETER
23. CLEAR/DISPLAY SWITCH-INDICATOR
24. 4/D/COURSE/ETE SWITCH-INDICATOR
25. HRS/W/BRG/RNG SWITCH-INDICATOR
26. ET INDICATOR
27. 1/A/STATUS SWITCH-INDICATOR
28. LEFT DIGITAL DISPLAY

228.225

Figure 2-62.—Typical control-indicator operating controls and indicators.

by ionospheric height, surface conductivity and, to some extent, the earth's magnetic field.

Variations in the height of the ionosphere (diurnal shifts) occur between night and day. The extent of these diurnal shifts can be as much as one percent and can cause daily changes in phase propagation velocity, which in turn will result in shifts of the isophase contours generated by any pair of Omega stations. Isophase contours form an electronic lattice which may be viewed as a grid slowly shifting back and forth over the earth's surface in a daily pattern following diurnal shifts of the ionosphere. Gradual changes in this pattern will occur as the ionosphere is affected by seasonal changes. The repetitive nature of this shifting lends a high degree of predictability to lattice movement. The United States Naval Oceanographic Office computes and publishes these predictions for each pair of transmitted signals in each geographic area of the earth's surface. Skywave correction factors are provided separately and must be applied to each of the receiver line-of-position readings to convert them to common Omega geographic map grids (similar to loran charts).

TYPICAL AIRBORNE OMEGA NAVIGATION SYSTEM

Since certain data, such as lane identity, must be derived and cross-checked with other means of navigation in order for the Omega navigation system to provide accurate and rapid navigation data, the Omega receivers had to be integrated with an aircraft computer. A typical Omega system is comprised of a control-indicator unit, a receiver-computer unit, and an antenna system.

The control-indicator provides the operator the means to perform man-machine functions by enabling the operator to insert specific navigational data into the receiver-computer unit, request specific data in the receiver-computer and/or current data for display, and display status of the Omega navigational set. The unit can also be used as part of the Omega set test station during maintenance of the Omega equipment. Figure 2-62 is a diagram of a typical control-indicator unit, with its operating controls and indicators. Table 2-5 explains the functions of the various controls and indicators. By observing the functions listed in table 2-5, you will have some idea of the overall capabilities of a typical system. The controls and indicators and their specific functions may vary slightly, depending on the specific receiver-computer utilized; however, the overall system concepts will be basically the same.

The receiver-computer unit contains the electronic circuitry which processes external navigational data, and processes Omega navigational data along with preprogrammed navigational data to provide current navigational information to the control-indicator for display.

Simplified Block Diagram Analysis

Figure 2-63 (foldout at the end of this chapter) is a simplified block diagram of an airborne Omega navigational system. Note that only the 10.2 kHz section is shown. The receiver section of the computer actually has identical circuits for the 11.3 and 13.6 kHz signals as well. All three sections function the same. Since the unique feature of the Omega system is its ability to provide rapid and accurate navigational data based on the computer software routines, the overall operational description provided is very brief. Subsequent paragraphs will provide a detailed description of the software routines performed by the computer to obtain the positional data.

The transmitted Omega signals received through the two orthogonal loop antennae are supplied to the antenna-coupler. The antenna-coupler filters and amplifies the Omega signals, and supplies the signals to the antenna filters. It also amplifies the Omega signals and supplies the signals to the antenna switching matrix in the receiver-computer group. The antenna switching matrix enables the computer to select an antenna configuration which will be best suited for the specific operation. The Omega signals passed through the input gate circuit in the antenna switching matrix are supplied to the receiver strips. Each receiver strip is tuned to a different Omega frequency. The receiver strip processes the Omega signal through amplifier and filter circuits in the RF and IF portions of the receiver.

Table 2-5.—Control indicator operating controls and indicators

FIG. 2-62 REF. NUMBER	CONTROL/INDICATOR	FUNCTION/PURPOSE
1	POS UNC/AMB	The illuminated POS UNC segment informs the operator that position variance is greater than 4 miles and the system is operating in the Difference Frequency mode. Also, the illuminated POS UNC segment informs the operator that Omega signals are weak due to insufficient number of signal acquisitions. The POS UNC will illuminate during initial turn-on until the oscillator is calibrated. The illuminated AMB segment informs the operator that more than one estimate of position exists in the system. Normally, this implies that signals from one station are in error or the system is receiving insufficient information to completely define its present position. Also, the AMB segment may illuminate during initial turn-on if the system has more than one estimate of oscillator starting time.
2	SYNC	The illuminated SYNC informs the operator that the system is in the synchronization mode. Upon completion of synchronization process, the SYNC indicator will go out. It will remain off until power is cycled or failure of the oscillator is detected.
3	PANEL HOLD switch-indicator	Enables the operator to initiate a hold condition which "freezes" current data displayed in the data register displays.
4	SYSTEM MALF indicator	The illuminated SYSTEM MALF informs the operator that a malfunction is detected during system self-test routine. Once illuminated, SYSTEM MALF will remain on until power is cycled or PANEL TEST switch-indicator is pressed.
5	RATE AID FAIL indicator	The illuminated RATE AID FAIL informs the operator that the system detects difference between True Airspeed and Groundspeed greater than 200 knots. The indicator also illuminates when the system is in the heading-hold mode.
6	Single character data displays	The two single character data displays are utilized to label certain data by illuminating alpha characters.

Table 2-5.—Control indicator operating controls and indicators—Continued

FIG. 2-62 REF. NUMBER	CONTROL/INDICATOR	FUNCTION/PURPOSE
7/28	Data register displays	The two data register displays are segmented lights which are used to display input data to the computer, data which has been stored in the computer, and current navigational data. The data is displayed in numerics only.
8	INS/N/POS switch-indicator	The illuminated INS segment informs the operator that normal North oriented navigation can be selected or that INS heading can be or is inserted. The illuminated N segment informs the operator that North (direction) latitude data can be selected for input to the computer. The illuminated POS segment informs the operator that current aircraft position (during initialization) can be inserted, is inserted or is displayed.
9	2/B/M-HDG switch	The illuminated 2 segment informs the operator that numeric 2 data can be inserted or indicates a specific fixed destination point. The illuminated B segment informs the operator that Omega station B is being used or displayed. The illuminated M-HDG segment informs the operator that heading data can be inserted or manual heading mode can be selected.
10	EP indicator	The illuminated EP indicator informs the operator that new aircraft position has not been entered since turn-on. The illuminated EP indicator will go out when new aircraft position is entered or "old" position is accepted.
11	3/C/M-VEL switch-indicator	The illuminated 3 segment informs the operator that numeric 3 data can be inserted or indicates a specific destination point. The illuminated C segment informs the operator that Omega station C is being used or displayed. The illuminated M-VEL segment informs the operator that velocity data can be inserted or the manual velocity mode can be selected.

Table 2-5.—Control indicator operating controls and indicators—Continued

FIG. 2-62 REF. NUMBER	CONTROL/INDICATOR	FUNCTION/PURPOSE
12	GRD/E/DEST-POS switch-indicator	The illuminated GRD segment informs the operator that grid mode navigation can be selected or is being used. The illuminated E segment informs the operator that East (direction) can be selected during longitude data input operation. The illuminated DEST-POS segment informs the operator that destination point can be entered or verify that stored position of selected destination is correct.
13	6/F/LOP switch-indicator	The illuminated 6 segment informs the operator that numeric 6 data can be inserted, or indicates a specific fixed destination point. The illuminated F segment informs the operator that Omega station F is being used or displayed. The illuminated LOP segment informs the operator that line of position data is being displayed.
14	9/HLD/MAN H-V switch-indicator	The illuminated 9 segment informs the operator that numeric 9 data can be inserted or indicates a specific fixed destination point. The illuminated HLD segment informs the operator that heading data can be held during changeover to or from grid mode navigation. The illuminated MAN H-V segment informs the operator that manual heading and velocity data can be selected or is displayed.
15	ACCEPT/INSERT switch-indicator	The illuminated ACCEPT segment informs the operator that inserted data should be verified by observing the display and, if valid, press ACCEPT to input that data into the computer. The illuminated INSERT segment informs the operator that insert routine can be initiated.
16	POWER switch-indicator	Enables the operator to energize the Omega Navigational Set. When actuated (POWER illuminated), computer power supply is activated and power is applied to the entire system.

Table 2-5.—Control indicator operating controls and indicators—Continued

FIG. 2-62 REF. NUMBER	CONTROL/INDICATOR	FUNCTION/PURPOSE
17	5/E/DATE/GMT	The illuminated 5 segment informs the operator that numeric 5 data can be inserted or indicates a specific fixed destination point. The illuminated E segment informs the operator that Omega station E is being used or displayed. The illuminated DATE/GMT segment informs the operator that date and Greenwich Time for use in Omega propagation prediction can be inserted or verify that current time and date is correct.
18	PANEL TEST switch-indicator	Enables the operator to initiate panel test which will automatically exercise the panel indicators in a series of tests. When completed, the panel will return to its quiescent state.
19	0S/TRACK/G-SPEED switch-indicator	The illuminated 0 segment informs the operator that numeric 0 data can be inserted or indicates a specific fixed destination point. The illuminated S segment informs the operator that South (direction) can be selected during latitude data input operation. The illuminated TRACK/G-SPEED segment informs the operator that computed angle measured from true North or grid North to a line representing the track and current computed speed of the aircraft along the track is displayed.
20	8/H/CTE	The illuminated 8 segment informs the operator that numeric 8 data can be inserted or indicates a specific fixed destination point. The illuminated H segment informs the operator that Omega station H is being used or displayed. The illuminated CTE segment informs the operator that computed perpendicular error, in miles between any two specific destination points, is displayed.

Table 2-5.—Control indicator operating controls and indicators—Continued

FIG. 2-62 REF. NUMBER	CONTROL/INDICATOR	FUNCTION/PURPOSE
21	7/G/WIND switch-indicator	The illuminated 7 segment informs the operator that numeric 7 data can be inserted or indicates a specific fixed destination point. The illuminated G segment informs the operator that Omega station G is being used or displayed. The illuminated WIND segment informs that computed value of wind based upon difference between computed groundspeed and true airspeed input data is displayed.
22	DIM potentiometer	Enables the operator to control the intensity of the front panel displays and switch-indicators.
23	CLEAR/DISPLAYS switch-indicator	The illuminated CLEAR segment informs the operator that current insert and display data can be cleared. The illuminated CLEAR segment also informs the operator that partial or entire entry of a multiple entry operation (latitude, longitude, etc.) can be cleared. The illuminated DISPLAY segment informs the operator that display function can be initiated or selected.
24	4/D/COURSE/ETE switch-indicator	The illuminated 4 segment informs the operator that numeric 4 data can be inserted or indicates a specific fixed destination point. The illuminated D segment informs the operator that Omega station D is being used or displayed. The illuminated COURSE/ ETE segment informs the operator that computer Great Circle Course (True and Grid) and estimated time based on current velocity from aircraft position to selected destination is displayed.
25	HRS/W/BRG/RNG switch-indicator	The illuminated HRS segment informs the operator that heading reference from the Attitude Heading Reference System can be selected or is being used. The illuminated W segment informs the operator that West (direction) can be selected during longitude data input operation. The illuminated BRG/ RNG segment informs the operator that computed Great Circle Bearing (Mag or Grid) and distance from aircraft position to selected destination are displayed.

Table 2-5.—Control indicator operating controls and indicators—Continued

FIG. 2-62 REF. NUMBER	CONTROL/INDICATOR	FUNCTION/PURPOSE
26	ET indicator	The illuminated ET indicator informs the operator that new date and time have not been entered since turn-on. The illuminated ET indicator will go out when new date and time are entered or "old" time and date accepted.
27	1/A/STATUS	The illuminated 1 segment informs the operator that numeric 1 data can be inserted or indicates a specific fixed destination point. The illuminated A segment informs the operator that Omega station A is being used or displayed. The illuminated STATUS segment informs the operator that special status is being displayed. Also, the illuminated STATUS segment informs the operator that different mode of operation data can be selected or entered.
28	NOTE: SEE #7	

The output from the IF portion is supplied to the phase correlator and digital converter, where it is mixed with reference signals provided by the precision frequency generator to obtain sine and cosine phase information. This sine and cosine phase information is converted into digital form required by the computer. This digital information is supplied to an accumulator in the receiver-computer group input/output circuit. When instructed by the computer, this information is supplied to the burst filter where the synchronization process will begin. When synchronization is obtained, the output from the burst filter is supplied to the tracking filter. The tracking filter further filters the burst filter output and processes this signal along with programmed data and data from external inputs. When this phase information is acceptable, it is supplied to the combinational filter where the signal is again filtered and processed along with additional programmed data. When the positional data obtained from the processing in the combinational filter is acceptable, the positional data is transferred through the input/output section to the control-indicator. The control-indicator processes the positional data from the computer through decoders to display the positional information on the front panel displays. This positional information is continually updated.

SYNCHRONIZATION.—In order to measure the phase of the incoming Omega bursts, the software system in the Omega system must align the transmitted Omega pattern with a known transmitted pattern. The two patterns must be aligned within 0.05 second. (See figure 2-64.) The method of synchronization is based on the fact that the 10-second period lacks symmetry. For example, a recorded 0.9-second burst must be followed by either a 1.0 or a 1.2-second burst. (Refer to fig. 2-60.) In either case, the total reception pattern can be identified.

It would appear that a data gathering period over a few seconds would produce at least two bursts which would then establish synchronization. However, the problem is that too often the signals are absent or are so buried in noise that

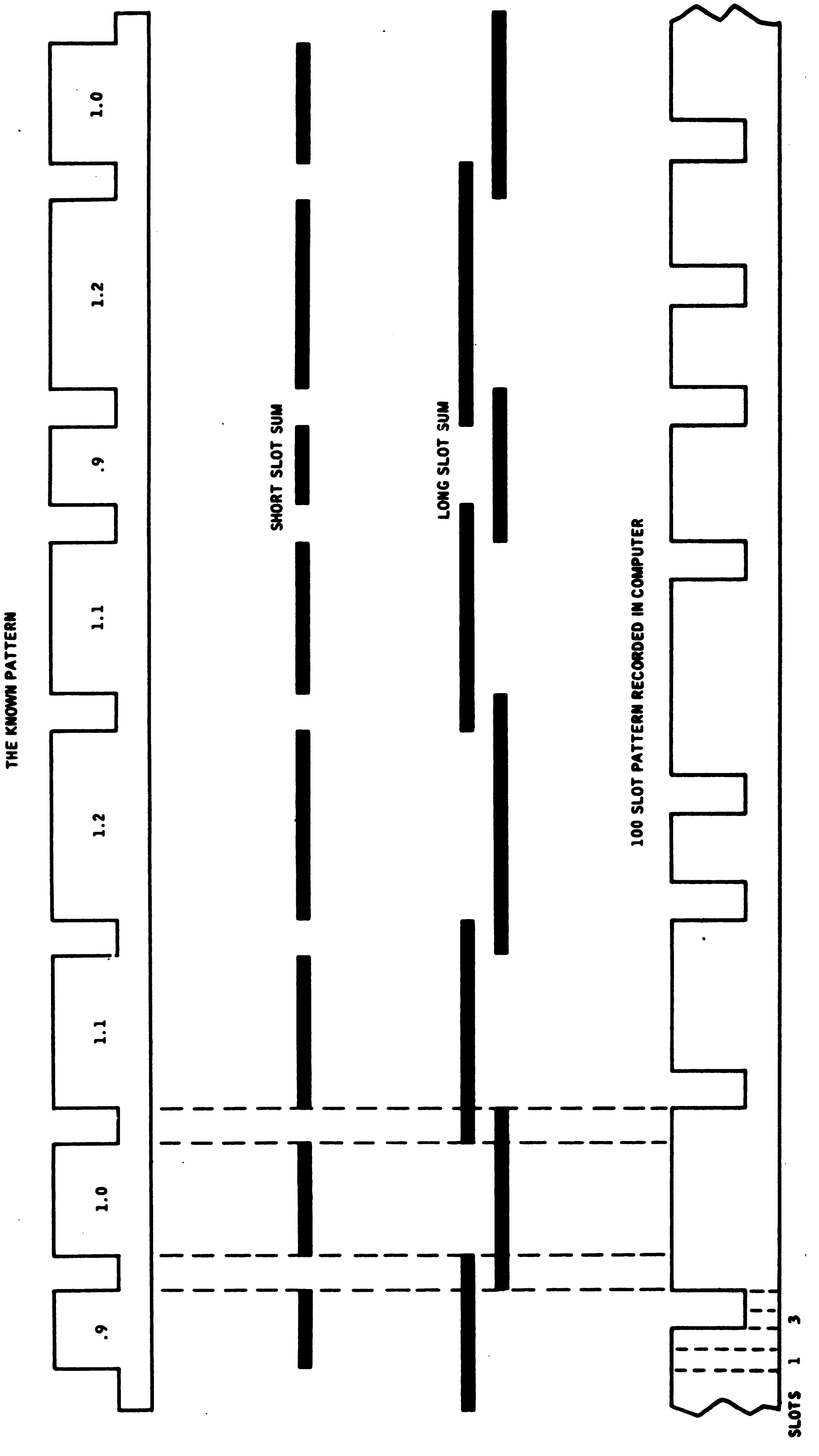


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Figure 2-64.—Omega signal synchronization.

an accurate time count of the burst length from any one station will be difficult. Therefore, the synchronization routine records a ten-second transmission period in increments of 0.1 second, starting at some arbitrary time. In this way, the received ten-second pattern is partitioned into 100 distinct entities or slots. The first four of these 100 slots are shown in figure 2-64. Then, to obtain synchronization, the slot numbers can be manipulated with the mathematical technique of differential correlation.

The mechanization is based upon the phase coherency of the bursts, as opposed to the incoherent phase relationship of the 0.2-second period of nontransmission between bursts. A slot number, representing a portion of a burst, is composed of a succession of 20 digital outputs from each of the sine and cosine correlators. These are phase measurements, but they contain an unknown phase shift which has been introduced by the antenna. During synchronization, the orthogonal loop antenna is used in a pseudo-omnidirectional mode which shifts the incoming phase measurement an amount, proportional to the station bearing, which is unknown until synchronization has been completed. However, the incorrect measured phase is unimportant, at this time, since all that is required to identify a burst is a succession of sign-consistent numbers from the correlators. These are summed to obtain the slot value. On the other hand, a slot number which represents a portion of a period between bursts is made up of the correlator sine and cosine outputs whose values are random because of the phase incoherency of white noise, and whose sum should be close to zero. Thus, a slot number representing a burst is a nonzero number.

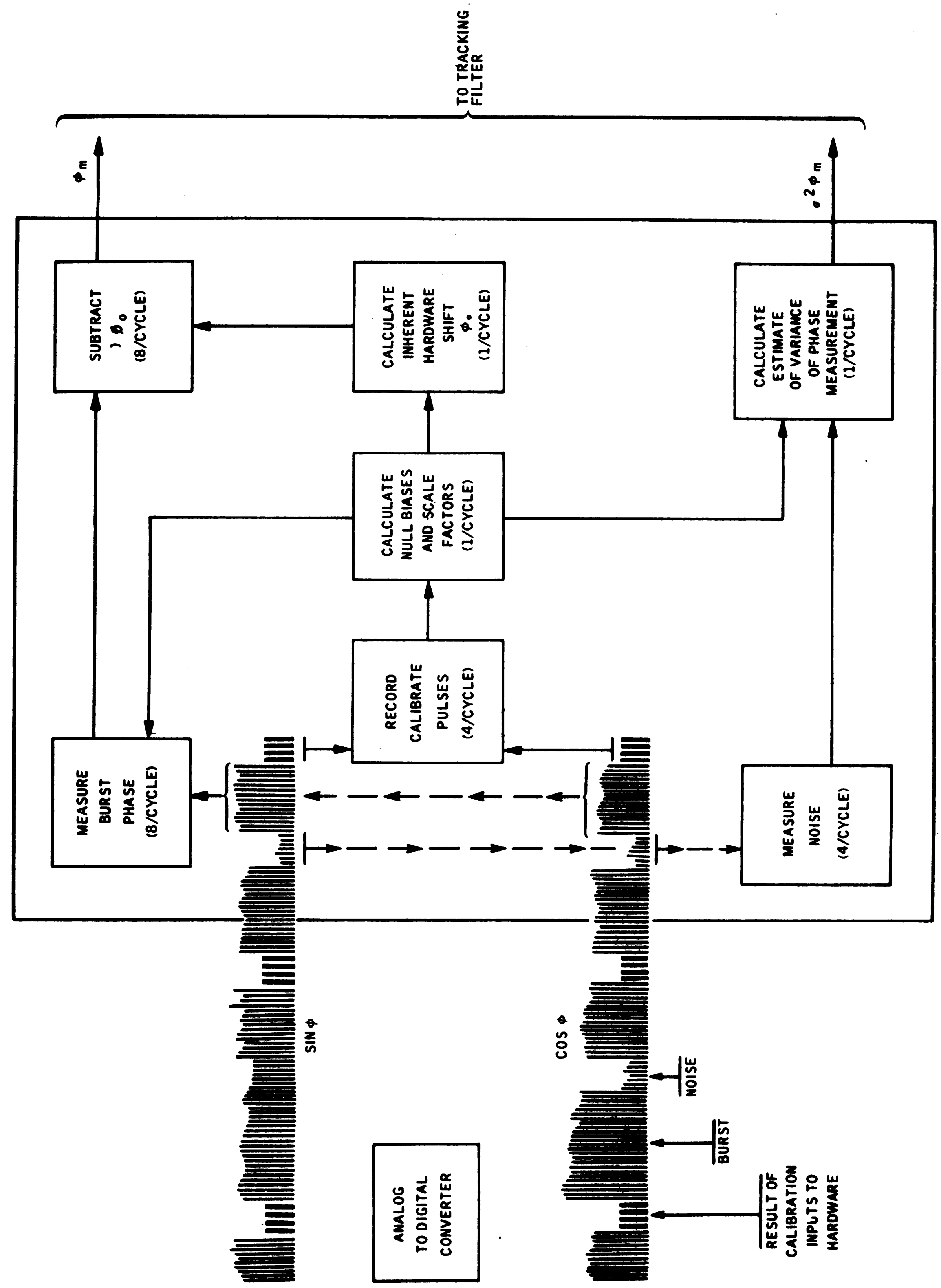
To match the transmitted burst to the known pattern, the synchronization routine uses the differential correlation technique which calculates the average squared value over a short-slot sum, and over a long-slot sum, then takes the difference. The short and long-slot sum pattern is illustrated in figure 2-64. After eight of these differences are obtained, they are summed and the resulting correlation number is associated with slot number 1. This process is repeated 100 times until the 100 possible start times in the 10-second period of station's transmission is exhausted. The 100 stored correlation values are then tested for the maximum. Confidence that synchronization is complete is based on comparing the extreme correlation value with the next best correlation value. When the best value exceeds the next best by a fixed amount, synchronization is complete. It is possible that the correlation test will not be satisfied by the value generated for the first ten-second period. Therefore, this process will be repeated for successive ten-second periods. This process will cycle through the three Omega frequencies using one of them in each of the ten-second periods. This will require one set of 100 X's and 100 Y's to be stored for future processing while the previous set is being used in the computation of the correlation values.

Burst Filter Routines.—The primary function of the burst filter is to obtain the first measure of burst phase and its variance. (See figure 2-65.) The burst filter also controls the antenna switching matrix to obtain an antenna configuration best suited for a specific operation.

Once synchronization has been verified, the burst filter can assign meaning to a sequence of digital (sine and cosine) outputs from the correlators. However, the correlators use dual slope integrators which probably have a bias which must be calibrated and filtered. To do this, a series of four test signals are injected, one at a time, into the receiver at every alternate period of nontransmission during a ten-second broadcast cycle. Using a known input, the output (measurement) from the dual slope integrator can be calibrated. There is also a phase shift introduced by the receiver hardware which must be subtracted from the burst phase measurement. The same calibration signals are recombined to yield this value.

Since there are eight nontransmission periods between bursts in a broadcast cycle, and four are used for calibration signals, this leaves four for measurement of noise (including spurious phantom signals which are internally generated). In this way, the signal-to-noise ratio is obtained, yielding a measure of phase credibility which will be identified as the estimate of phase measurement variance and supplied to the tracking filter for further processing.

The antenna switching matrix is controlled by the burst filter. The burst filter antenna


TO TRACKING FILTER
ϕ_m
$\sigma^2\phi_m$
SUBTRACT) ϕ_o (8/CYCLE)
CALCULATE INHERENT HARDWARE SHIFT ϕ_o (1/CYCLE)
CALCULATE ESTIMATE OF VARIANCE OF PHASE MEASUREMENT (1/CYCLE)
MEASURE BURST PHASE (8/CYCLE)
CALCULATE NULL BIASES AND SCALE FACTORS (1/CYCLE)
RECORD CALIBRATE PULSES (4/CYCLE)
MEASURE NOISE (4/CYCLE)
SIN φ
COS φ
NOISE
BURST
ANALOG TO DIGITAL CONVERTER
RESULT OF CALIBRATION INPUTS TO HARDWARE

228.228

Figure 2-65.—Burst filter routine block diagram.

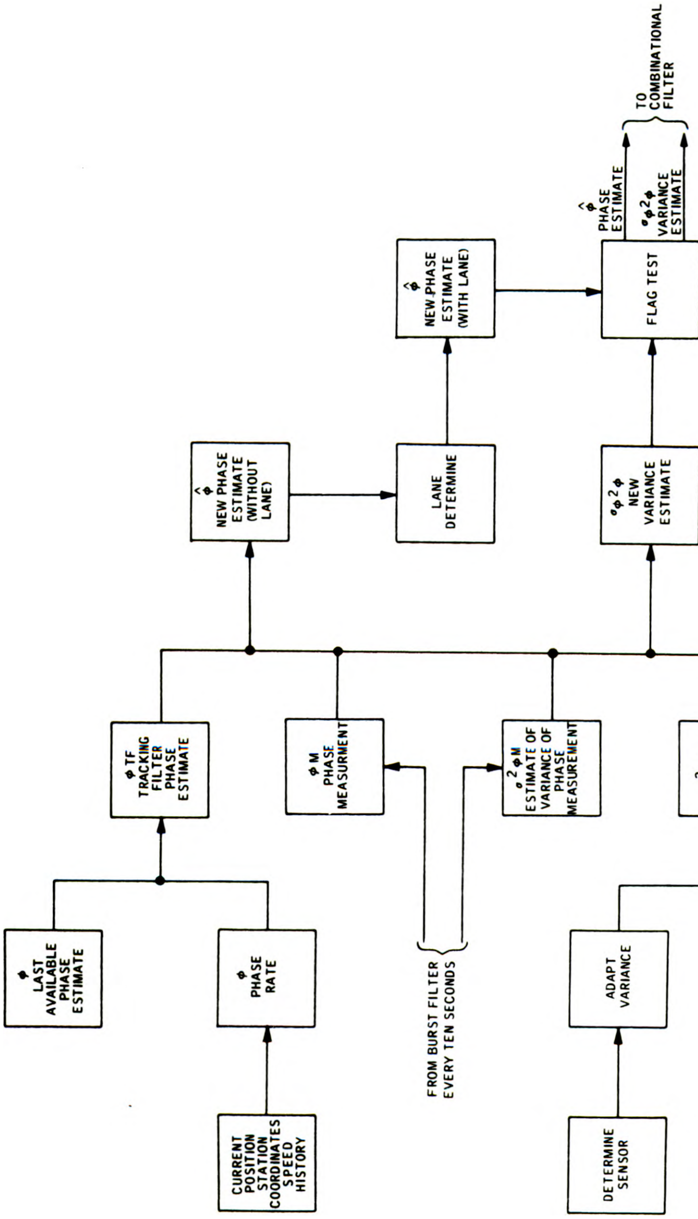
selection program uses aircraft heading and the known station location in the antenna selection routine to maximize the incoming burst signal-to-noise ratio. In effect, this increases the sensitivity of the orthogonal loop antenna to the incoming burst signal. This is accomplished by controlling the input gates in the antenna switching matrix to allow signals from loop A, loop B, or one of their negative values to enter the receiver strip.

Tracking Filter.—There are 24 distinct adaptive tracking filters provided in the system. (See figure 2-66.) One is provided for each of the three Omega frequencies and one for each of the eight Omega stations. Inputs to the tracking filters consist of measurement of phase and a computed variance of this measurement provided by the burst filter. This measure phase is then compared with an estimated value of phase, which the tracking filter computed based upon previous measurements, to provide a new estimate of phase. In order to compare average successive phase measurements spaced ten seconds apart in time, it is necessary to remove the effect of the change in phase due to aircraft speed. To accomplish this task, velocity information from an external source must be provided for the tracking filters. The external sources providing velocity information are external navigational equipment, or a manually inserted velocity information, or a manually inserted heading. The velocity inputs to the tracking filter consist of the north and east components of velocity averaged over the previous time interval. The tracking filter then computes the component of velocity along the direction from the aircraft to the transmitting station. This phase rate is then used to update the tracking filter phase estimate over the ten-second interval since the last measurement.

In addition to estimating phase, the tracking filter also estimates phase-rate error. This is the error in phase-rate as computed from the velocity source. The estimated phase-rate error is used to correct the computed phase-rate-in-time update of the phase estimate. In addition to computing estimated phase and phase-rate error, the tracking filter also computes the variance of error in estimating phase, the variance of error in estimating phase-rate error, the cross variance of error in estimating phase, and phase-rate error. It is the computation of these variances along with the phase determined by the burst filter that allows the tracking filter to statistically average the output from the burst filter and the new estimated phase at the tracking filter to obtain a single phase measurement and a single confidence number. That is, if the variance (confidence) is less than a specified number, the tracking filter "throws up a flag" which informs the combinational filter that new data is ready for processing. If the variance is too large, the tracking filter will not throw up a flag and the combinational filter will bypass tracking filter output on the next iteration. The tracking filter will continue this averaging until the variance is low enough to pass the "flag test."

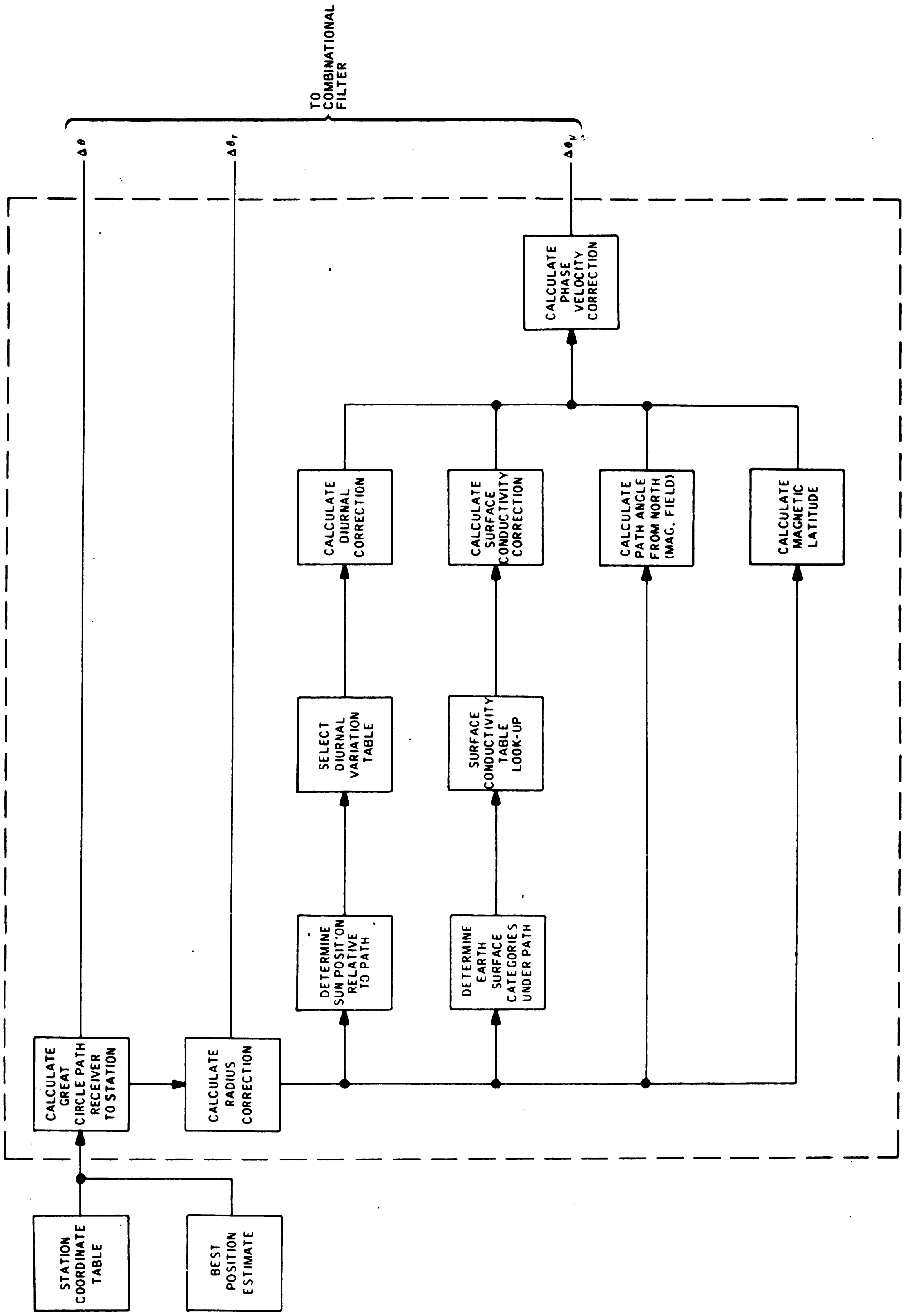
PROPAGATION PREDICTION ROUTINE.—The output from the propagation prediction routine is an input to the combinational filter. (See figure 2-67.) Thus far, the computer has concentrated on determining a precise phase estimate of the incoming bursts. Knowing this phase and the locations of the eight stations, we can establish our exact location. However, phase velocity must be calculated and supplied to the combinational filter to obtain an accurate position data. The spherical earth correction, phase velocity correction, and radius correction must be calculated and supplied to the combinational filter. The phase velocity is calculated by determining where the broadcast stations are located with respect to the Omega receiver, where the sun is located with respect to the great circle paths between the receiver and the stations, the classification of earth surfaces under those paths, the path angle of the intersection to the earth's magnetic field, and the magnetic latitude of the receiver.

Combinational Filter.—Inputs to the combinational filter are provided by the tracking filters and the propagation prediction circuit. (See figure 2-68.) The combinational filter provides a means of computing optimal estimates of position and velocity along with other elements of its state vector. The filter also performs the coordinate conversion from phase to geodetic coordinates (latitude and longitude) and lane determinations. The combinational filter utilizes


φ LAST AVAILABLE PHASE ESTIMATE
φ̇ PHASE RATE
CURRENT POSITION STATION COORDINATES SPEED HISTORY
φTF TRACKING FILTER PHASE ESTIMATE
φM PHASE MEASUREMENT
FROM BURST FILTER EVERY TEN SECONDS
σ²φM ESTIMATE OF VARIANCE OF PHASE MEASUREMENT
σ²TF VARIANCE ESTIMATE
ADAPT VARIANCE
DETERMINE SENSOR
LAST AVAILABLE ESTIMATE
φ̂ NEW PHASE ESTIMATE (WITHOUT LANE)
LANE DETERMINE
φ̂ NEW PHASE ESTIMATE (WITH LANE)
σφ²φ NEW VARIANCE ESTIMATE
FLAG TEST
φ̂ PHASE ESTIMATE
σφ²φ VARIANCE ESTIMATE
TO COMBINATIONAL FILTER

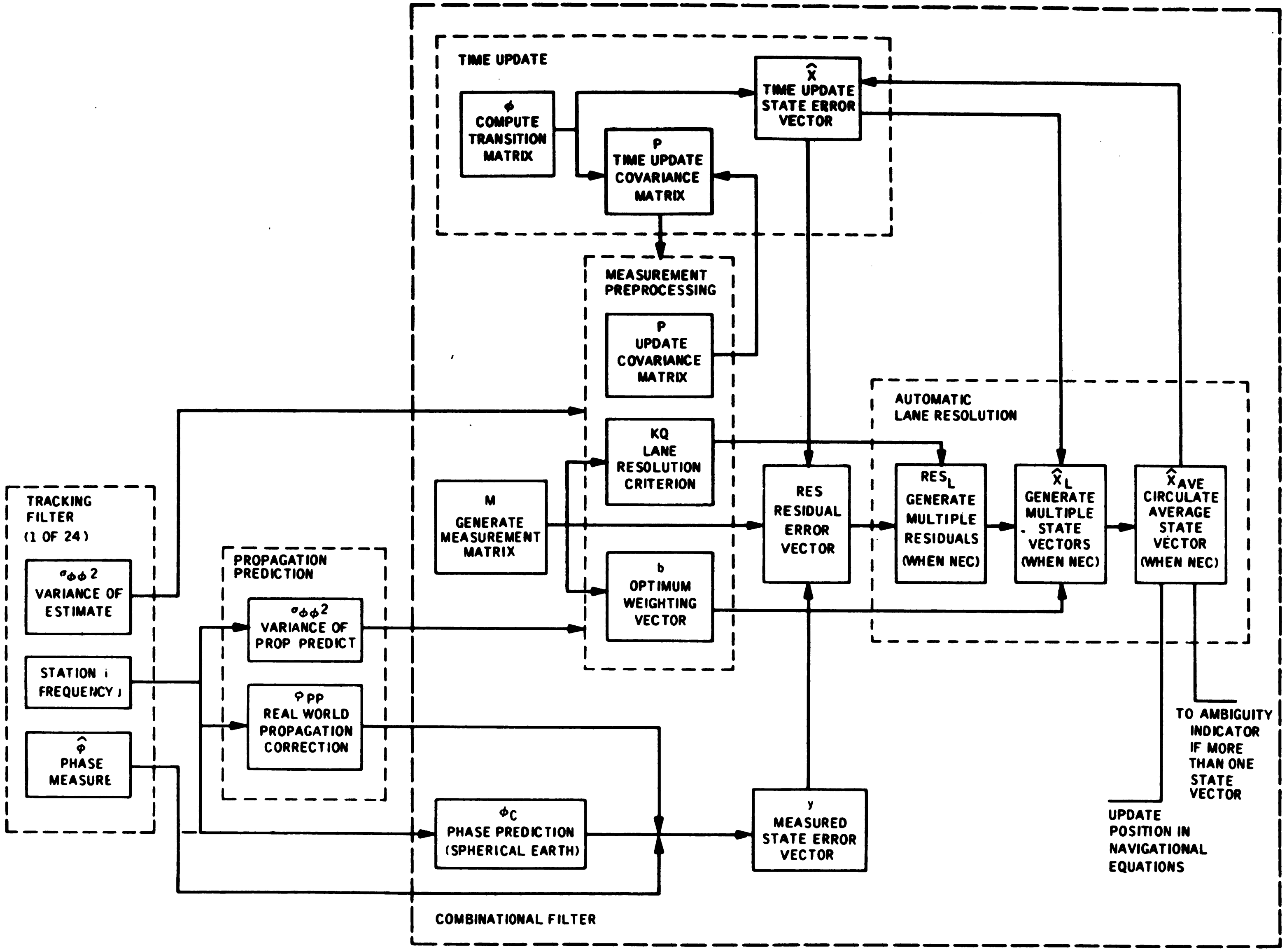
228.229

Figure 2-66.—Tracking filter routine block diagram.


TO COMBINATIONAL FILTER
$\Delta\theta$
$\Delta\theta_r$
$\Delta\theta_v$
STATION COORDINATE TABLE
BEST POSITION ESTIMATE
CALCULATE GREAT CIRCLE PATH RECEIVER TO STATION
CALCULATE RADIUS CORRECTION
DETERMINE SUN POSITION RELATIVE TO PATH
SELECT DIURNAL VARIATION TABLE
CALCULATE DIURNAL CORRECTION
DETERMINE EARTH SURFACE CATEGORIES UNDER PATH
SURFACE CONDUCTIVITY TABLE LOOK-UP
CALCULATE SURFACE CONDUCTIVITY CORRECTION
CALCULATE PATH ANGLE FROM NORTH (MAG. FIELD)
CALCULATE MAGNETIC LATITUDE
CALCULATE PHASE VELOCITY CORRECTION

228.230

Figure 2-67.—Propagation prediction routine block diagram.

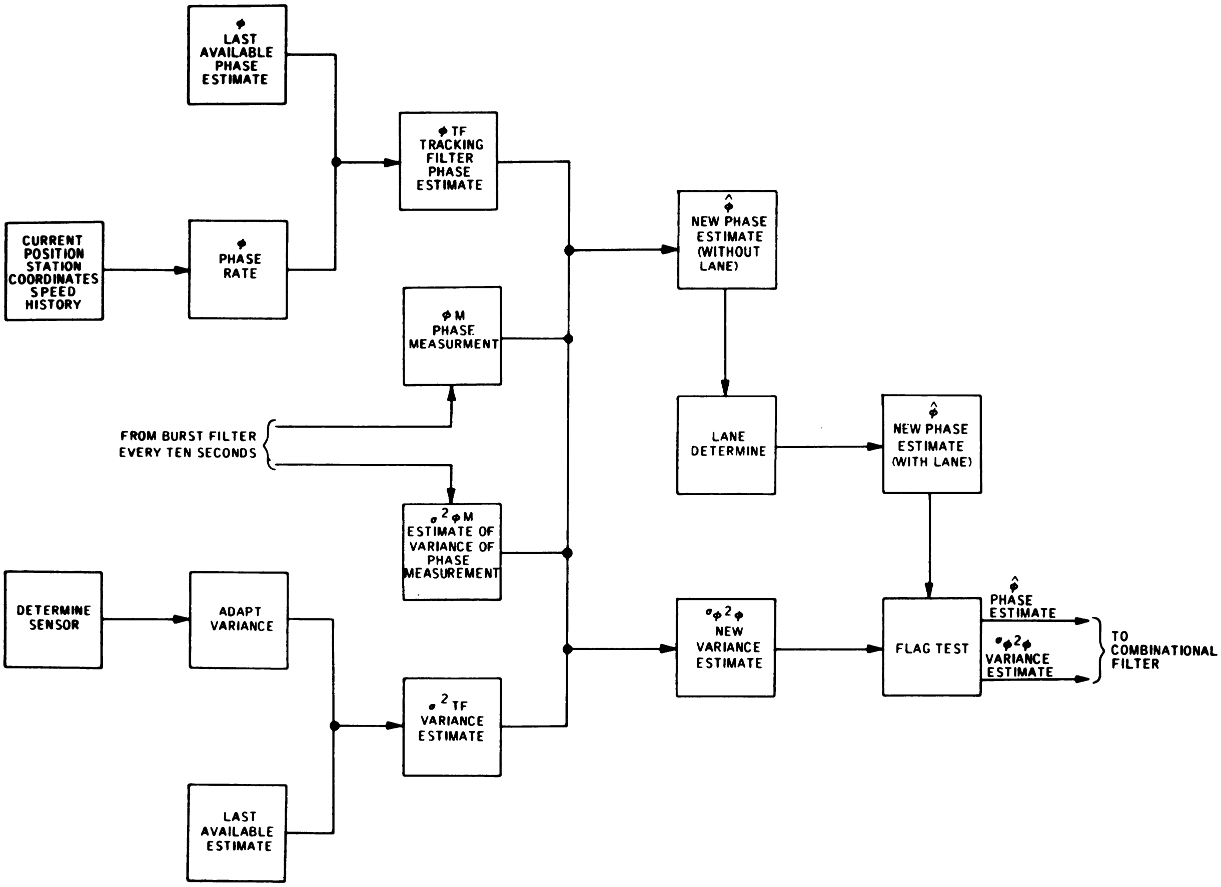

TIME UPDATE
ϕ COMPUTE TRANSITION MATRIX
P TIME UPDATE COVARIANCE MATRIX
$\hat{X}$ TIME UPDATE STATE ERROR VECTOR
MEASUREMENT PREPROCESSING
P UPDATE COVARIANCE MATRIX
KQ LANE RESOLUTION CRITERION
b OPTIMUM WEIGHTING VECTOR
M GENERATE MEASUREMENT MATRIX
RES RESIDUAL ERROR VECTOR
AUTOMATIC LANE RESOLUTION
RES_L GENERATE MULTIPLE RESIDUALS (WHEN NEC)
$\hat{X}_L$ GENERATE MULTIPLE STATE VECTORS (WHEN NEC)
$\hat{X}_{AVE}$ CIRCULATE AVERAGE STATE VECTOR (WHEN NEC)
TO AMBIGUITY INDICATOR IF MORE THAN ONE STATE VECTOR
UPDATE POSITION IN NAVIGATIONAL EQUATIONS
TRACKING FILTER (1 OF 24)
$\sigma_{\phi\phi}2$ VARIANCE OF ESTIMATE
STATION i FREQUENCY j
$\hat{\varphi}$ PHASE MEASURE
PROPAGATION PREDICTION
$\sigma_{\phi\phi}2$ VARIANCE OF PROP PREDICT
φ_{PP} REAL WORLD PROPAGATION CORRECTION
ϕ_C PHASE PREDICTION (SPHERICAL EARTH)
y MEASURED STATE ERROR VECTOR
COMBINATIONAL FILTER

228.231

Figure 2-68.—Combinational filter routine block diagram.

two types of observations. One is the difference between the phase of the tracking filter and a value of phase based upon the combinational filter's updated position. The other consists of a received correction to position entered through the control-indicator. Based on these measurements, the combinational filter computes optimal estimates of: position errors, driving velocity errors, oscillator zero time, oscillator drift, and propagation parameters. Once the system errors are determined, the combinational filter updates its estimates of all system errors. In addition, the estimate of system "goodness," the co-variance matrix, is updated to reflect the inclusion of this new information. The estimates that result from using multiple frequencies are then combined to remove the ambiguity arising from the multiple Omega lanes. The combinational filter also predicts, in its time update, how the system errors will increase as a function of time and how the "goodness" of the system deteriorates with time. This estimate of system "goodness" is then used to determine the optimum weighing when subsequent measurements are made. The recursive character of the filter allows long data strings of past measurements to be combined into a few parameters; thus, the entire system operation resides with the last estimate. This optimal estimate of the state of the system is called the state vector.

Various receiver-computer routines differ slightly and are only explained here to give you the basic Omega system concepts. If you now have a broad concept of the Omega navigation system, the preceeding information has served its purpose. To fully understand a particular receiver-computer in a particular aircraft, refer to the applicable technical manual for the theory of operation.


φ LAST AVAILABLE PHASE ESTIMATE
φTF TRACKING FILTER PHASE ESTIMATE
CURRENT POSITION STATION COORDINATES SPEED HISTORY
φ PHASE RATE
φ̂ NEW PHASE ESTIMATE (WITHOUT LANE)
φM PHASE MEASURMENT
FROM BURST FILTER EVERY TEN SECONDS
LANE DETERMINE
φ̂ NEW PHASE ESTIMATE (WITH LANE)
σ²φM ESTIMATE OF VARIANCE OF PHASE MEASUREMENT
DETERMINE SENSOR
ADAPT VARIANCE
σφ²φ NEW VARIANCE ESTIMATE
FLAG TEST
φ̂ PHASE ESTIMATE
σφ²φ VARIANCE ESTIMATE
TO COMBINATIONAL FILTER
σ²TF VARIANCE ESTIMATE
LAST AVAILABLE ESTIMATE

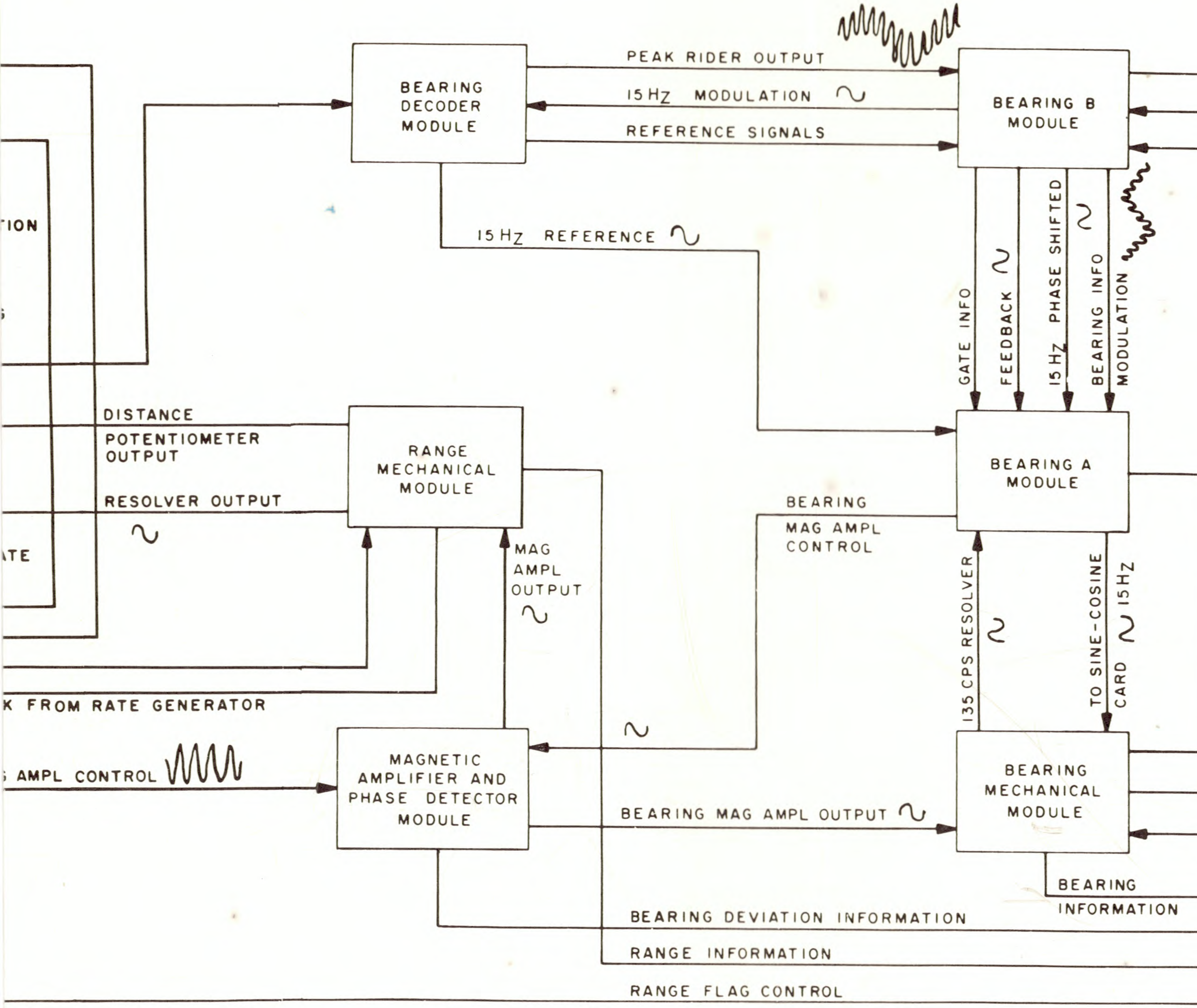
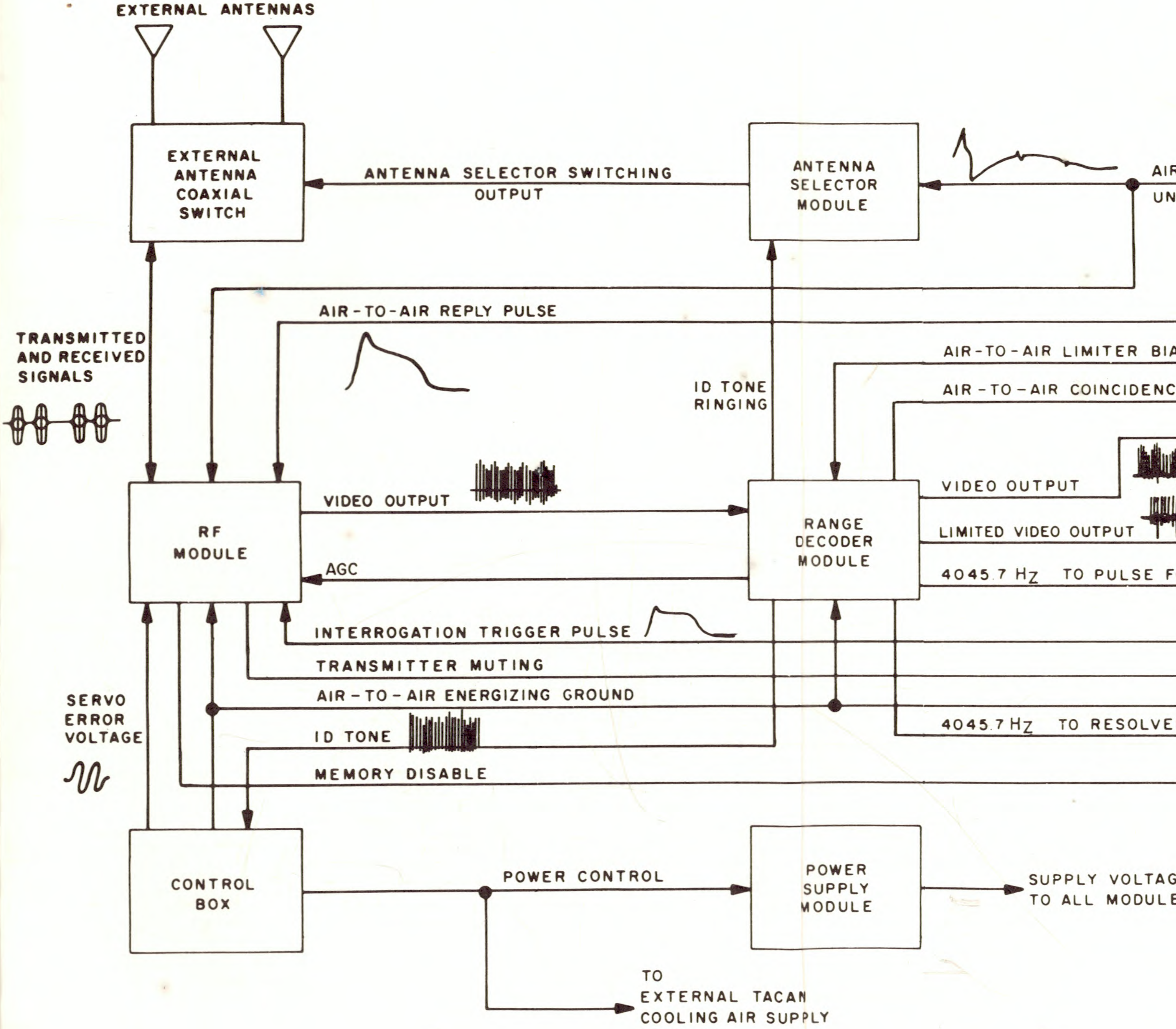


Figure 2-29.—Overall system block


EXTERNAL ANTENNAS
EXTERNAL ANTENNA COAXIAL SWITCH
ANTENNA SELECTOR SWITCHING OUTPUT
ANTENNA SELECTOR MODULE
AIR
UN
TRANSMITTED AND RECEIVED SIGNALS
AIR-TO-AIR REPLY PULSE
ID TONE RINGING
AIR-TO-AIR LIMITER BIA
AIR-TO-AIR COINCIDENC
RF MODULE
VIDEO OUTPUT
RANGE DECODER MODULE
VIDEO OUTPUT
LIMITED VIDEO OUTPUT
AGC
4045.7 Hz TO PULSE F
INTERROGATION TRIGGER PULSE
TRANSMITTER MUTING
SERVO ERROR VOLTAGE
AIR-TO-AIR ENERGIZING GROUND
ID TONE
4045.7 Hz TO RESOLVE
MEMORY DISABLE
CONTROL BOX
POWER CONTROL
POWER SUPPLY MODULE
SUPPLY VOLTAG
TO ALL MODULE
TO EXTERNAL TACAN COOLING AIR SUPPLY

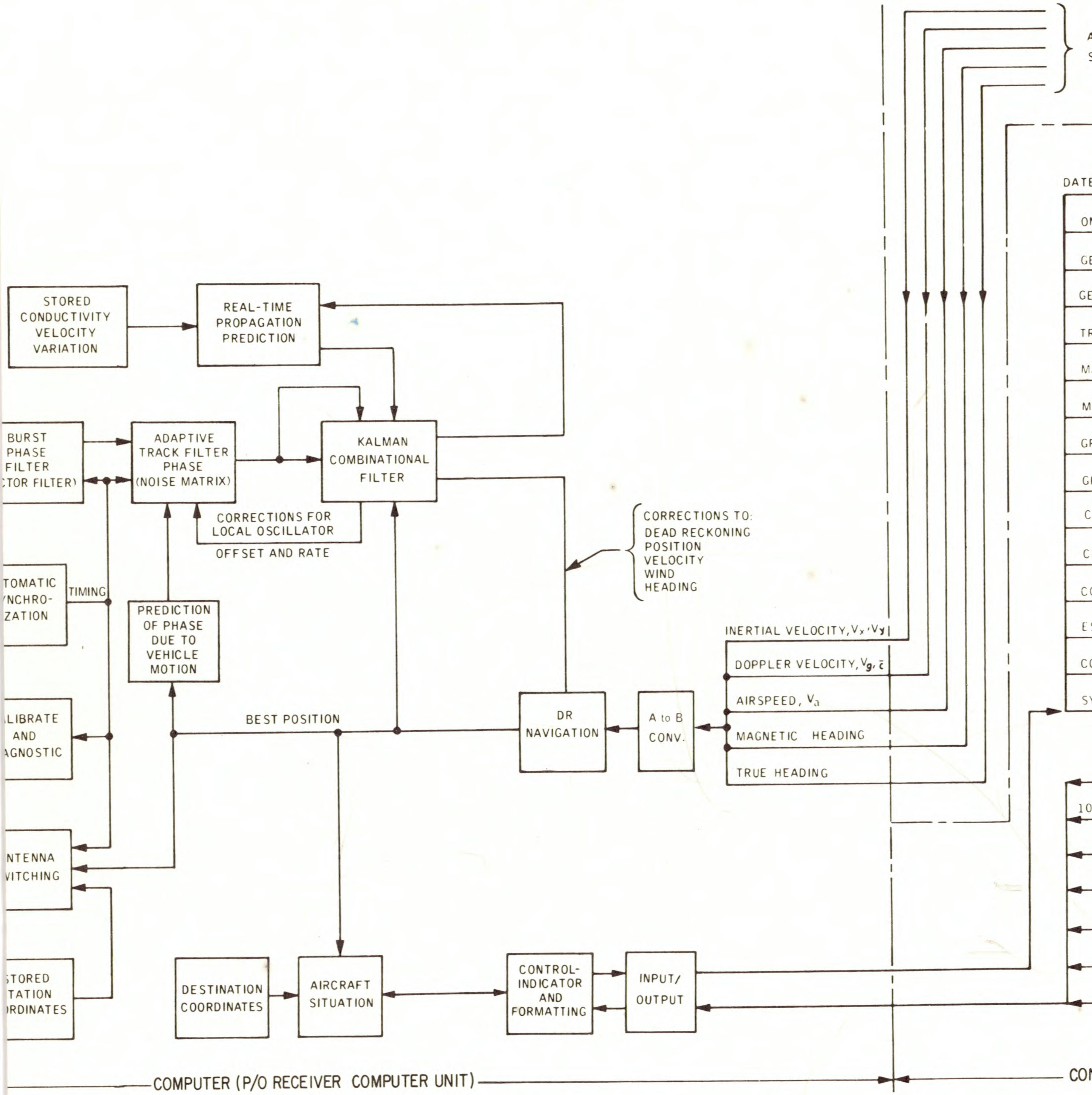
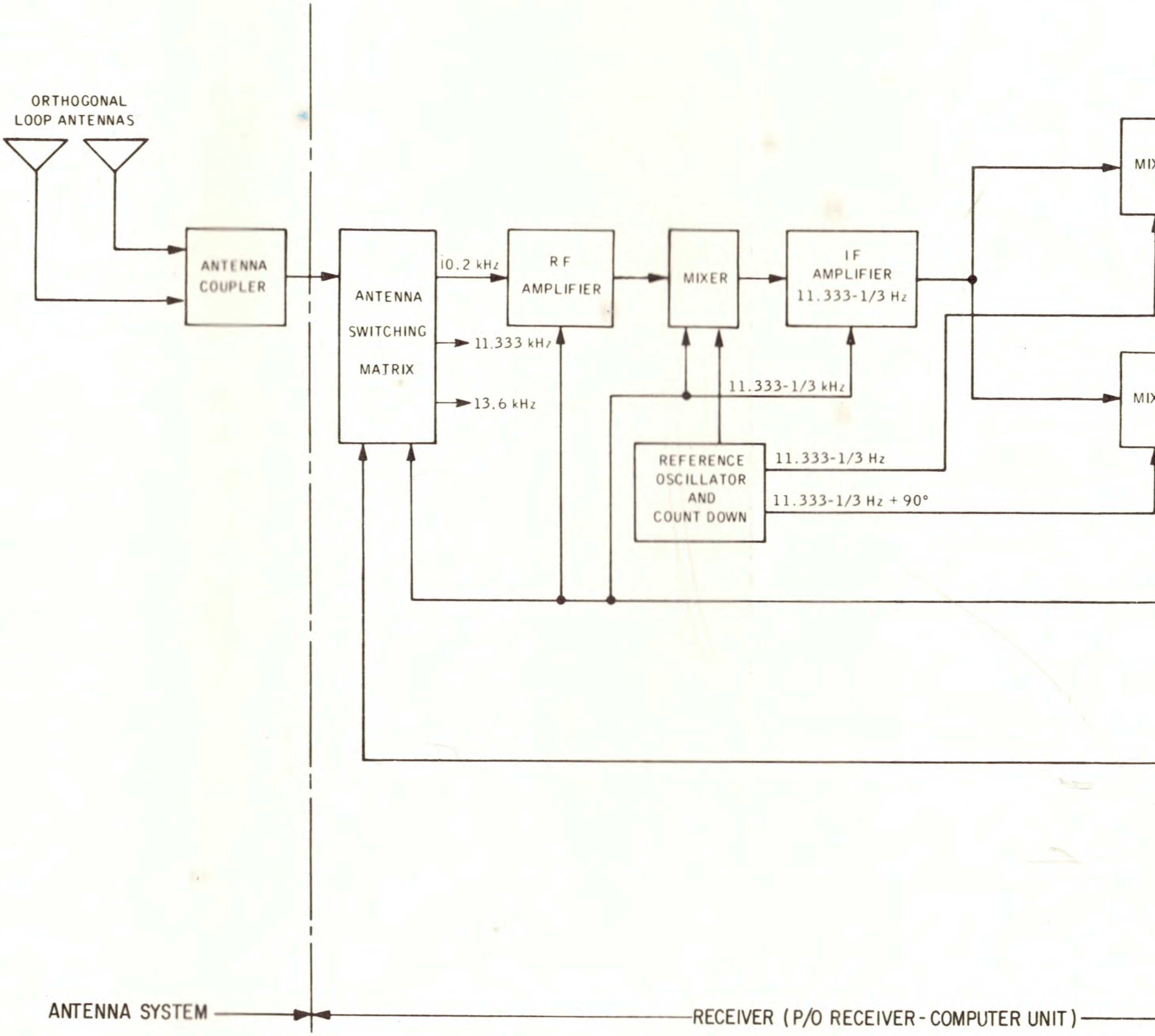

STORED CONDUCTIVITY VELOCITY VARIATION
REAL-TIME PROPAGATION PREDICTION
BURST PHASE FILTER
TOR FILTER)
ADAPTIVE TRACK FILTER PHASE (NOISE MATRIX)
KALMAN COMBINATIONAL FILTER
CORRECTIONS FOR LOCAL OSCILLATOR OFFSET AND RATE
TOMATIC YNCHRO- ZATION
TIMING
PREDICTION OF PHASE DUE TO VEHICLE MOTION
CORRECTIONS TO: DEAD RECKONING POSITION VELOCITY WIND HEADING
LIBRATE AND AGNOSTIC
BEST POSITION
DR NAVIGATION
A to B CONV.
INERTIAL VELOCITY, Vx, Vy
DOPPLER VELOCITY, Vg, ε
AIRSPEED, Va
MAGNETIC HEADING
TRUE HEADING
NTENNA WITCHING
TORED TATION RDINATES
DESTINATION COORDINATES
AIRCRAFT SITUATION
CONTROL-INDICATOR AND FORMATTING
INPUT/OUTPUT
COMPUTER (P/O RECEIVER COMPUTER UNIT)
CON
DATE
OM
GE
GE
TR
M
M
GR
G
C
C
CO
E
CO
SY
10
A
S

Figure 2-63.—Typical OMEGA Navigation Set Func


ORTHOGONAL LOOP ANTENNAS
ANTENNA COUPLER
ANTENNA SWITCHING MATRIX
10.2 kHz
11.333 kHz
13.6 kHz
R F AMPLIFIER
MIXER
I F AMPLIFIER 11.333-1/3 Hz
11.333-1/3 kHz
REFERENCE OSCILLATOR AND COUNT DOWN
11.333-1/3 Hz
11.333-1/3 Hz + 90°
MIX
MIX
ANTENNA SYSTEM
RECEIVER (P/O RECEIVER-COMPUTER UNIT)

CHAPTER 3

RADAR AND IFF

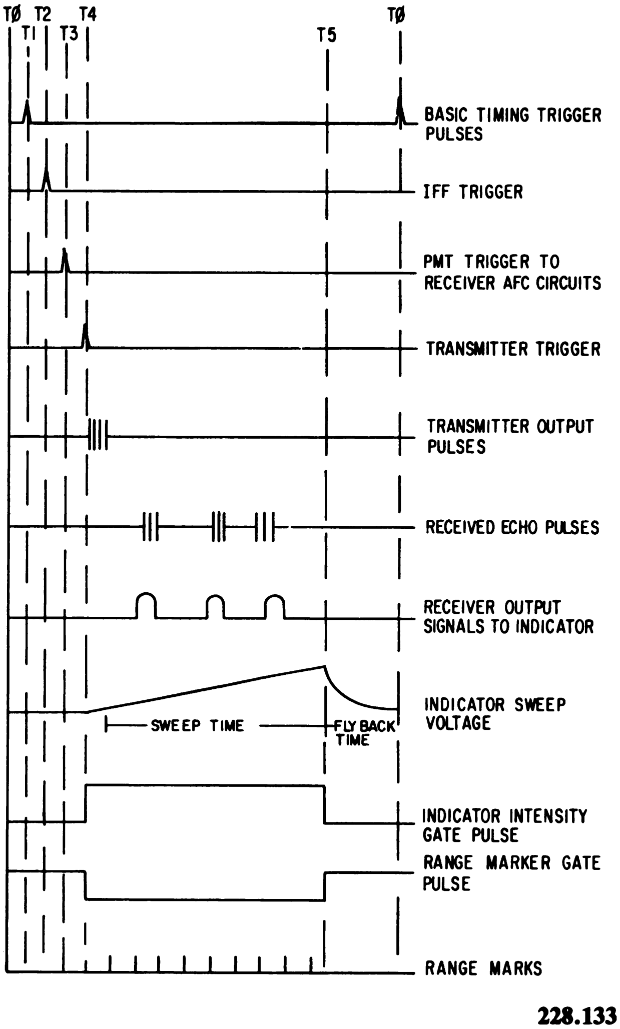
In Chapter 4 of *Avionics Technician 3 & 2 (Part 1)*, we discussed the principles of radar, and briefly described a fundamental radar system and the purpose of the various system components. For these components to accomplish their purpose, many circuits (including some that are special) are required.

While *Basic Electronics, Volume 2*, NAVEDTRA 10087 (Series), and the *Navy Electricity and Electronics Training Series (NEETS)* modules covered many circuits, they did not include some that you will encounter in a typical pulse-type radar. Such circuits are described in this chapter.

Since all targets appear as a spot of light on a radar indicator, a means of identifying friendly targets is required. The IFF (identification, friend or foe), working in conjunction with radar, accomplishes this task. As a technician, you need to know how IFF operates and its integration with radar displays. This chapter will give basic information to aid you in understanding these systems.

SYNCHRONIZER

The basic function of the radar synchronizer is timing. Specifically, the synchronizer produces the trigger pulses that start the transmitter, the indicator sweep circuits, range marker generating circuits, blanking and unblanking circuits, AFC (automatic frequency control) circuits, and various gating circuits. Figure 3-1 shows the basic timing relationships of a typical radar system.


T0
T1
T2
T3
T4
T5
T0
BASIC TIMING TRIGGER PULSES
IFF TRIGGER
PMT TRIGGER TO RECEIVER AFC CIRCUITS
TRANSMITTER TRIGGER
TRANSMITTER OUTPUT PULSES
RECEIVED ECHO PULSES
RECEIVER OUTPUT SIGNALS TO INDICATOR
INDICATOR SWEEP VOLTAGE
SWEEP TIME
FLY BACK TIME
INDICATOR INTENSITY GATE PULSE
RANGE MARKER GATE PULSE
RANGE MARKS

228.133

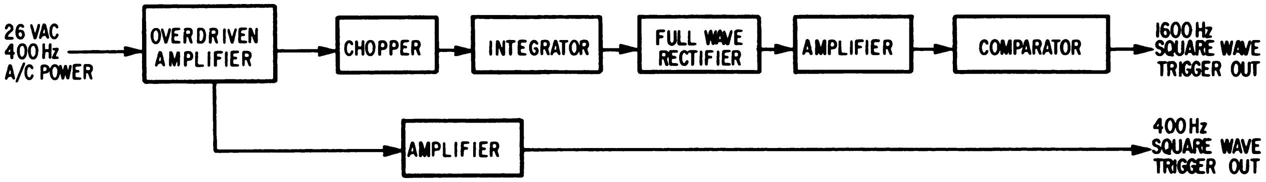
Figure 3-1.—Time relationships of radar system triggers and waveforms.

Timing or control is the function of most of the circuits in radar. The circuits accomplish these functions by producing a variety of voltage waveforms such as sine waves, square waves, sawtooth waves, differentiated waves, and pulse spikes. Although the circuits are broadly classified as timing or control circuits, the specific function of any individual circuit might be timing (such as a stabilized oscillator), wave generating (such as a sawtooth generator), or wave shaping (such as an RC differentiator circuit).

The basic timing trigger pulses generated by the radar synchronizer are initiated by either a master oscillator or a frequency-converter circuit which uses the aircraft's 400-Hz power source as its basic timing trigger input.

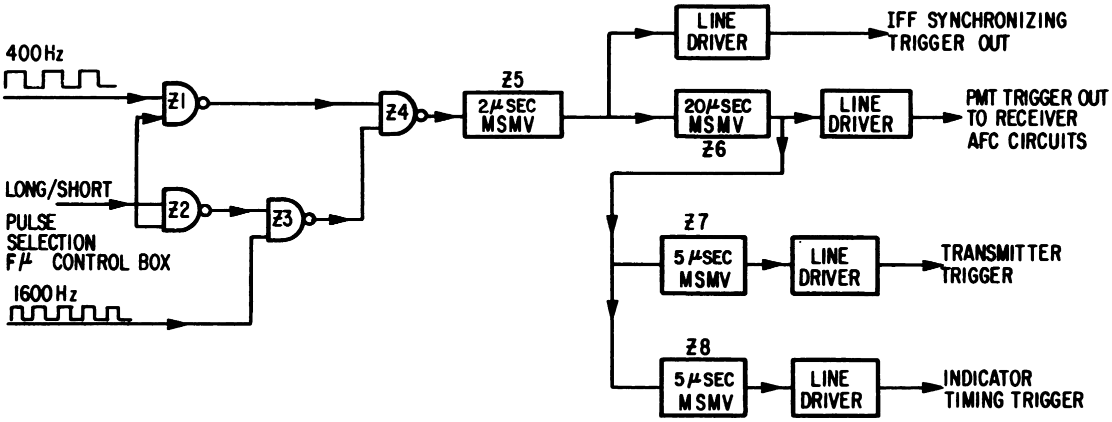
Figure 3-2 is a block diagram of a typical radar synchronizer frequency-converter circuit using the aircraft's 26 V ac 400-Hz power source as its basic timing source. The output of the converter is 400-Hz and 1600-Hz square waves. This output is fed to a logic circuit which will develop the required basic triggers for either long or short pulse modes of operation of the radar system. Figure 3-3 is a simplified diagram of a typical delay and inhibit logic circuit, which uses the 400-Hz and 1600-Hz square waves out of a frequency converter to generate the required radar timing triggers to establish the time relationships shown in figure 3-1. The mode of operation (long or short pulse width) is selected on the radar control panel by the operator. This puts either a logic 1 for long pulse, or a logic 0 for short pulse, into Z1 and Z2 (fig. 3-3). With a logic 1 applied, NAND gate Z1 is enabled and the 400-Hz square wave is applied to Z4. The same logic 1 enables Z2, and puts a logic 0 to one input of Z3, giving a constant 1 out of Z3. This logic 1 enables Z4, and the 400-Hz signal is allowed to trigger the monostable multivibrator (MSMV) Z5. Being a 2 μsec MSMV, 2 μsec after time 0, an IFF trigger is generated. This trigger will be used to synchronize the IFF and radar, which will be covered later in this chapter. The output of Z5 also triggers Z6. Twenty μsec later a pre-master trigger (PMT) is generated, which will gate the receiver's AFC circuits. This will be explained later in this chapter when we discuss the AFC circuits.

The output of Z6 is used to trigger Z7 and Z8, and 5 μsec later, a transmitter trigger is



228.134

Figure 3-2.—Synchronizer frequency converter simplified block diagram.



228.135

Figure 3-3.—Typical synchronizer delay and inhibit logic simplified functional flow diagram.

generated. In addition, an indicator trigger, which will start the indicator's sweep generating and range mark generating circuits, is also generated. In this manner, the transmitter, receiver, and indicator circuits are synchronized. The actual times of trigger generation will vary from radar to radar depending on the pulse repetition frequency (prf) and the specific use of the radar system.

For short pulse mode of operation, a logic 0 is applied to Z1 and Z2. This inhibits the 400-Hz signal from being passed by Z1. The logic 0 applied to Z2 puts a logic 1 on one input to gate Z3. This allows the 1600-Hz signal to pass through Z3. The output of Z1 is a steady logic 1 and this enables Z4, allowing the 1600 Hz to trigger the MSMV Z5 in the same manner as the 400-Hz signal did. The difference in the output triggers will be that the prf of the radar is now much higher (four times as high), but the time relationships between the IFF, pre-master trigger, transmitter, and indicator triggers remain the same. The indicator sweep circuits and range marker circuits will also change their prf.

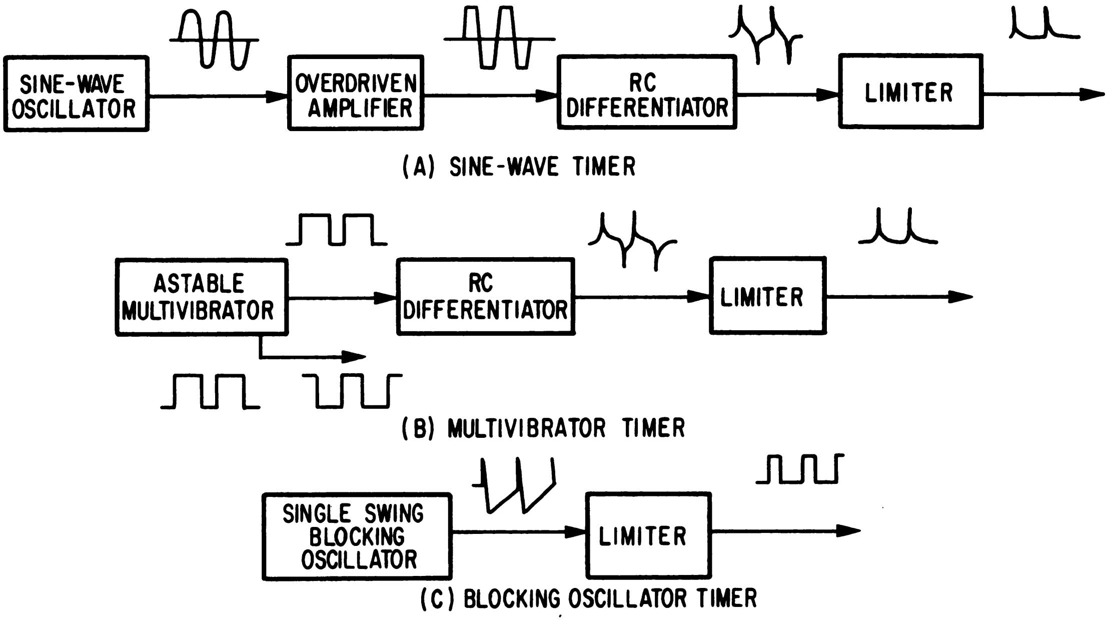
In radars using a master oscillator for basic timing, the oscillator may be a sine-wave oscillator, an astable multivibrator (free running), or a blocking oscillator.

When a blocking oscillator is used as the master oscillator, the output timing trigger pulses are usually obtained directly from the oscillator. When a sine-wave oscillator or multivibrator is used, pulse forming circuits (as shown in figure 3-4), are required to shape the pulse. The output of these basic timers can then be delayed, or otherwise influenced, in much the same manner as the frequency converter outputs just discussed, to give the proper timing sequence for the system.

PLAN POSITION INDICATOR (PPI)

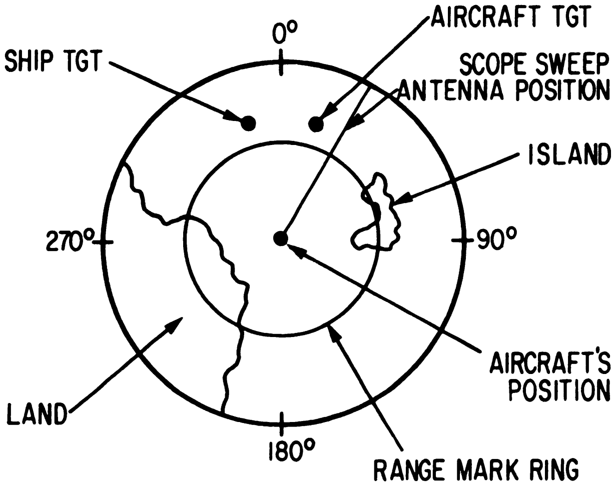
As explained in *Basic Electronics, Volume 2*, there are various types of radar displays. However, the one most widely used with aircraft radars is the PPI display.

The PPI display is used when it is desired to track objects on a 360° polar map, giving range and azimuth. This map can easily be correlated with standard maps, since the physical features



222.85

Figure 3-4.—Typical basic timing master oscillator circuits.



228.136

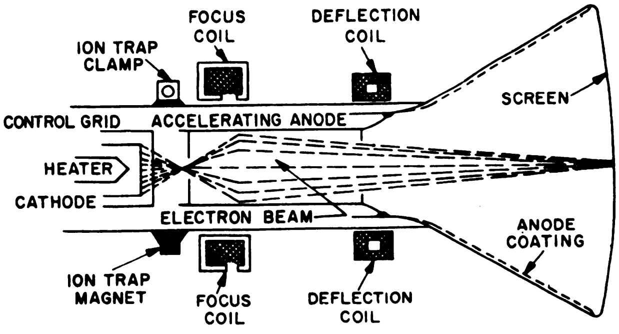
Figure 3-5.—Typical PPI display.

of the presentation are made apparent. Figure 3-5 is a drawing of a typical PPI display. The shape of the land coast and the island on the display match that of a standard map.

ELECTROMAGNETIC CATHODE-RAY TUBE

The PPI indicator is a type of radar display which uses an electromagnetic cathode-ray tube (CRT). Figure 3-6 is a pictorial representation of an electromagnetic CRT. The CRT uses a triode-type gun. It consists of an indirectly heated cylindrical cathode closed off at one end by a small plate, which is coated with barium and strontium oxides. The oxides emit a large number of electrons. A twisted heater element is contained within the cylindrical cathode to bring the cathode to the operating temperature. The control grid, also a cylinder, surrounds the cathode cylinder. It contains a baffle with a tiny aperture of smaller diameter than the emitting surface of the cathode, which is located very close to the aperture.

Beyond the control grid is a hollow cylinder which contains several baffles and has its circumference around the same axis as the control grid. This cylinder is the accelerating anode which is connected to a conductive coating within the tube. This coating acts as an extension of the accelerating anode and as an electrostatic shield. There is no second anode for focusing as there is in the electrostatic CRT. Instead, an external focusing coil encircles the neck of the tube and magnetically focuses the electron beam. The complete focusing system is composed of two lenses. One is produced by the electrostatic field between the control grid and the following electrode. This electrostatic field causes the electron beam to converge at a point some distance before the magnetic field of the focusing coil which acts as the second lens. After the electrons travel beyond the convergent point they again begin spreading until they enter the magnetic field of the focusing coil. There the reaction causes the electrons to later converge at the phosphorescent screen, if the position of the coil and the current through the coil are correct. The position of this external focusing coil is capable of being varied along the neck of the tube, and the physical construction of the coil also permits one side of it to come in closer proximity to the tube than the other. This characteristic of the focusing coil provides a means of centering the electron beam as well as of focusing it.



228.137

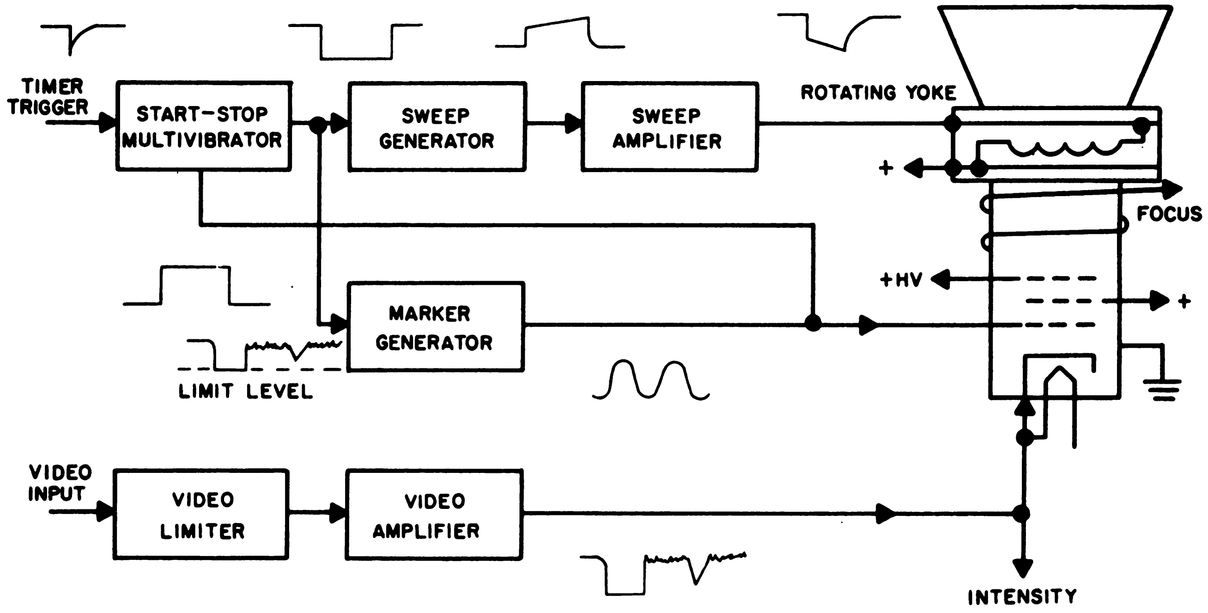
Figure 3-6.—Electromagnetic cathode-ray tube.

The method of accomplishing horizontal and vertical deflection also relies on an external electromagnetic force. This electromagnetic force is provided by a set of coils, which encircles the neck of the CRT and is located after the focus coil. Usually four deflection coils are used. Two of these are wired in series and are mounted to produce a magnetic field whose lines of force run vertically through the neck of the tube. This vertical magnetic field causes horizontal deflection of the electron stream. The other pair of coils is wired in series and mounted to produce a magnetic field whose lines of force run horizontally through the neck of the tube. This horizontal magnetic field causes a vertical deflection of the electron stream. A current is used to activate the coils and produce the magnetic fields at right angles to the electron movement. The amount of deflection that may be obtained is dependent upon accelerating anode voltage, distance between the screen and the deflection coils, length of the magnetic field, and the strength of the magnetic field. These deflection coils are contained in a mounting and are called the deflection yoke. The position of the deflection yoke, like the position of the focus coil, can be shifted along the neck of the tube to vary the amount of deflection. The deflection yoke can also be rotated about the neck of the tube. This property permits the visual pattern or raster to be centered squarely on the screen.

Another element used on an electromagnetic CRT is called the ion trap. It removes a problem that is peculiar to the electromagnetic CRT. Negative ions exist in the CRT as a result of the bombardment of the residual gas or tube electrodes by the emitted electrons. This condition is of no consequence in an electrostatic CRT since electrostatic focusing networks can focus the ions along with the electrons. In the electromagnetic CRT, however, the greater mass of the ion itself prevents proper focusing and deflection of these ions. The result is a constant bombardment of the screen at one particular spot, causing the gradual deterioration of the phosphorescent material at this point and a dark spot on the screen. There are several types of ion traps that may be used. One type consists of a modified electron gun arrangement and a permanent bar magnetic unit which is slipped around the neck of the tube close to the electron gun. Although it is not shown in the illustration, the gun is made to produce a bent electrostatic field that carries both ions and electrons toward the accelerating anode. The ion-trap magnet affects only the electrons in this combined beam in such a way that they change their direction of motion and return toward the main axis of the tube. In this manner only the electrons strike the screen, while the ions strike the anode and are removed.

PPI CIRCUITS

Figure 3-7 is a simplified block diagram of a typical PPI indicator. The circuits depicted

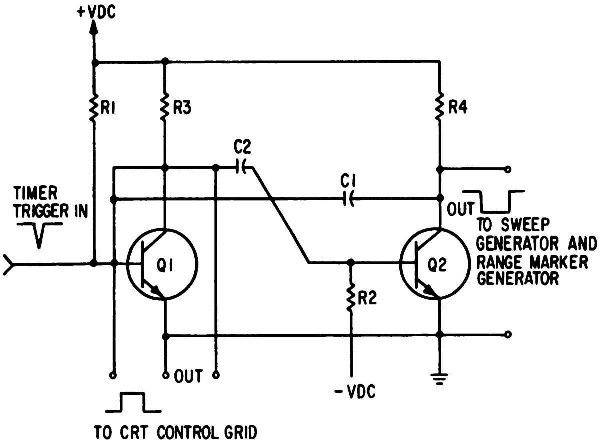


228.138

Figure 3-7.—Simplified PPI-scan block diagram.

do not necessarily represent every circuit that could be used in PPI displays, but they are the ones most commonly found in such displays. The timing trigger is a negative pulse which comes from the radar synchronizer. The start-stop multivibrator produces negative gate signals which are applied to the indicator's sweep generator and range marker generator, and a positive gate signal which is applied as an unblanking gate to the control grid of the CRT. A typical start-stop multivibrator is shown in figure 3-8. Resistors R1 and R2 are base bias resistors for Q1 and Q2 respectively. Resistors R3 and R4 are the collector resistors for Q1 and Q2 respectively. Capacitor C1 couples the base of Q1 to the collector of Q2. Capacitor C2 couples the base of Q2 to the collector of Q1.

Normally Q1 is conducting due to the positive bias applied to the base of Q1. At the same time, Q2 is normally cut off due to the fixed negative bias applied to the base of Q2. A negative pulse applied to the base of Q1 reduces conduction of Q1, causing the collector voltage to increase. The positive collector voltage swing of Q1 coupled across C2 to the base of Q2 causes Q2 to conduct, thereby decreasing the collector voltage of Q2. This decrease (negative swing) is fed back via C1 to the base of Q1 causing it to cut off. The circuit now rests in the opposite condition with Q2 conducting and Q1 cut off. During this period the flat portion of the output pulse is generated. Since capacitor C1 is connected to the positive voltage supply through R1, it eventually develops a positive charge which is sufficient to bring the base of Q1 above cutoff. Once again, Q1 conducts and the negative collector voltage swing is coupled by C2 to the base of Q2, driving it toward cutoff and producing the trailing edge of the output square wave as its collector voltage rises. Eventually Q1 is brought to the state of maximum conduction and Q2 is brought to cutoff, where the circuit stabilizes due to the positive biasing of Q1 and the negative biasing of Q2. Another timing pulse must be applied to Q1 in order to change the conduction states of Q1 and Q2.

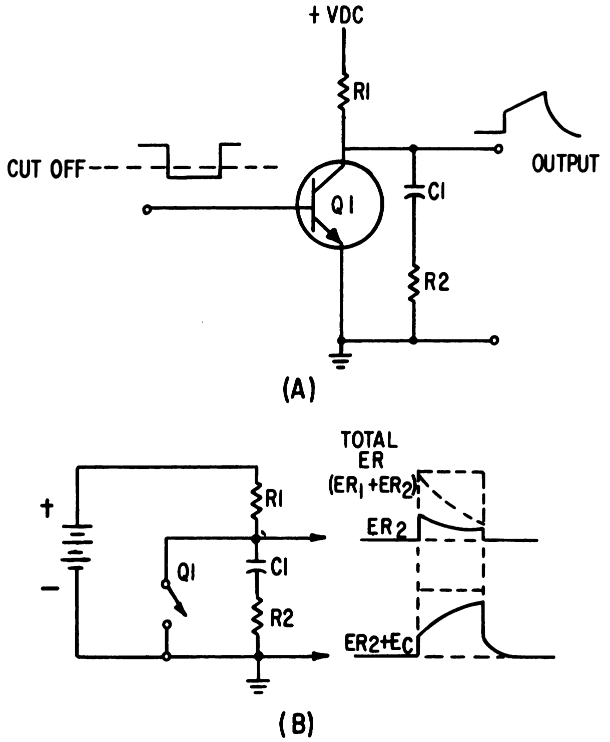


228.139

Figure 3-8.—Typical start-stop multivibrator.

From the description of the circuit operation of the start-stop multivibrator, it can be seen that for each timing trigger input from the synchronizer, one negative output gate appears at the output of Q2. This negative gate is used to operate the sweep generator and range marker generator. At the same time, a positive gate is obtained from the output of Q1, and is applied to the control grid of the CRT for unblanking purposes. The typical sweep generator, which receives the output from the start-stop multivibrator, produces a trapezoidal sweep. Figure 3-9A is a schematic of a typical sweep generator circuit. The negative rectangular pulse is applied to the base of Q1, which acts as a high-speed switch. Resistor R1 is the collector resistor of Q1. It is also part of an RC network, which determines the amplitude of the leading edge and the slope of the trapezoidal waveform, when Q1 is cut off. Resistor R2 is also part of the RC network when Q1 is cut off. Its value also affects the amplitude of the leading edge of the output waveform. Capacitor C1 is the capacitive part of the RC network. Its value affects the slope of the trapezoidal waveform.

When no input pulse is applied, Q1 is conducting and effectively shunting R2 and C1. As the negative rectangular input pulse is applied to the base of Q1, conduction of Q1 ceases and the collector voltage rises toward the supply value, generating the leading edge of the trapezoidal sweep waveform. The cutting off of Q1 acts the same as opening a switch, and causes capacitor C1 and resistor R2 to be brought into the circuit action. An equivalent circuit with corresponding waveforms is shown in figure 3-9B.



228.140

Figure 3-9.—A. Typical sweep generator; B. Equivalent trapezoidal generator circuit.

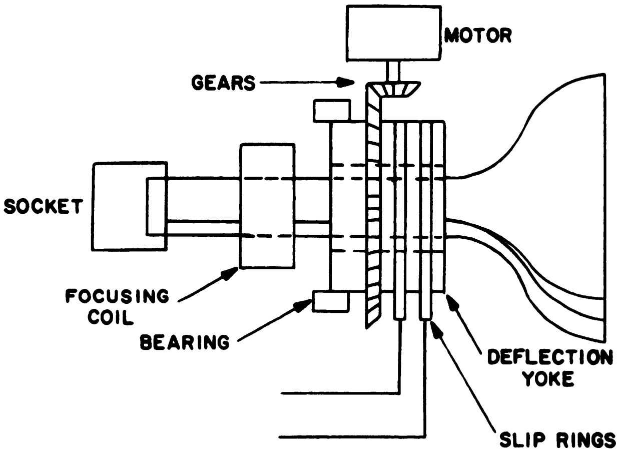
Capacitor C1 charges up toward the value of the collector supply voltage through resistors R1 and R2 at a rate dependent on the product of C1 times the sum of R1 and R2. The output is taken across capacitor C1 and resistor R2. Thus, as capacitor C1 charges, the voltage drop across R1 appears at the output. The output voltage increases toward the collector voltage supply at the charging rate of capacitor C1 until the end of the negative rectangular input pulse occurs. At this time, the positive trailing edge drives Q1 into conduction, removing capacitor C1 and resistor R2 from the circuit action by effectively closing the triode switch shown in the equivalent circuit of the sweep generator. The circuit remains in this state until the next negative rectangular pulse is applied to the input. The resultant output waveform is a trapezoidal pulse for every negative rectangular pulse applied to the input.

The trapezoidal output pulse is applied to a sweep amplifier where it is amplified before being applied to the sweep coil circuit. The sweep amplifier is normally a beam power amplifier which is required to provide sufficient current to the deflection circuits. The deflection coils may require from 50 to 100 milliamperes of current for maximum deflection.

When it is applied to the deflection coils, the trapezoidal waveform actually resolves into a sawtooth waveform due to the reactance of the coil.

The PPI sweep starts at the center of the CRT, and moves radially outward to the periphery of the CRT. The sweep trace position is made to indicate target bearing (or azimuth) by rotating it in synchronization with antenna rotation. This can be accomplished by any of several methods in two general categories. The first category uses a mechanical azimuth sweep, which provides a means of physically rotating the deflection yoke in synchronization with the antenna. This may be accomplished by using synchronous motors connected to the same power supply which drives the antenna and the deflection yoke; or it may be accomplished by using electromechanical repeaters to provide proper synchronization. Figure 3-10 illustrates how deflection is produced for the CRT shown in figure 3-7.

The second category uses an electrical azimuth sweep with a stationary deflection yoke. The amplitudes of the sawtooth sweep currents are varied sinusoidally, from zero to maximum,

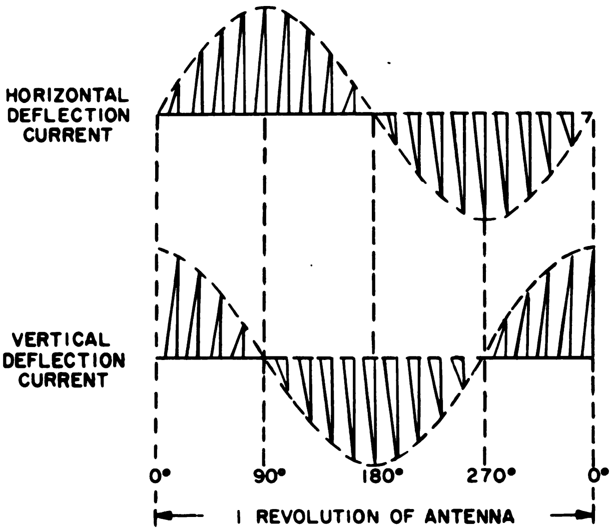


228.141

Figure 3-10.—Mechanical azimuth sweep.

corresponding to the rotation of the antenna. Furthermore, there is a 90° phase difference between the amplitude variations of the horizontal and vertical sawtooth waveforms. The sinusoidal variation is such that at maximum amplitude of the vertical sawtooth signal, the sweep will extend from the center of the CRT to the top of the CRT, or the maximum vertical position, which usually represents north. The amplitude of the horizontal deflection sawtooth waveform is zero at this time. Thus, the sweep does not extend in the horizontal direction at all. If the sweep were to represent east, or 90° east of the direction of travel, the horizontal deflection sawtooth amplitude would be maximum and the vertical deflection sawtooth amplitude would be minimum, or zero. Once the sweep travels beyond east, or 90° east of the direction of travel, the amplitude of the vertical sawtooth becomes negative; and, once the sweep travels beyond south, or 180° from the direction of travel, the horizontal sawtooth amplitude becomes negative also. Figure 3-11 shows the deflection coil currents for electrical azimuth sweep.

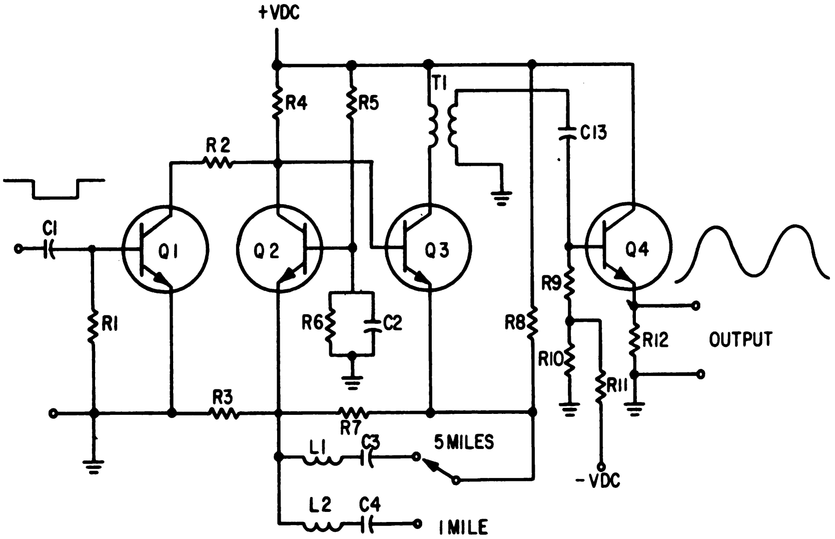
To obtain two sinusoidally varying sawtooth waveforms having a 90° phase difference, a rotary transformer is used. This transformer resembles a small electric motor and has two secondary windings, which are mounted at right angles to each other in the stator housing. The primary is mounted on the rotor, which is driven by the rotating antenna. A trapezoidal-wave generator is connected to the primary winding by means of slip rings. As the rotor is turned, the voltage obtained from either secondary varies. Maximum voltage is obtained from one secondary when zero voltage is obtained from the other. The transformer is so constructed that the amplitude of the output voltage varies sinusoidally with the rotor angle. The amplitudes of the trapezoidal output voltages, then, vary sinusoidally, and are 90° apart in phase. The trapezoidal output voltages are applied to separate power amplifiers. The required sawtooth sweep currents are obtained at the output of the power amplifiers. Sweep clampers are usually used to keep the reference level constant, and to cause every sweep to start at the same point on the CRT.



228.142
Figure 3-11.—Deflection coil currents for electrical azimuth sweep.

It was mentioned previously that the start-stop multivibrator has an output applied to the control grid of the CRT and to the marker generator, as well as to the sweep generator. A positive gate produced by the multivibrator is applied to the CRT control grid. This positive pulse increases the electron flow between the cathode and the face of the CRT, and permits the intensity of the trace to increase during the period that the timing pulse is applied. This is in reality an unblanking gate which permits the CRT to be operated at the desired time.

The negative output pulse (fig. 3-7) from the start-stop multivibrator is applied to the marker generator to trigger the production of range marks on the screen of the CRT. These range marks provide a means of determining the distance to a target from the origin (center of the scope). A typical range marker generator is shown in figure 3-12. It is made up of four transistors, the first of which (Q1) acts as a switch for transistors Q2 and Q3, which can only conduct when Q1 is cut off. Q2 and Q3 form a complete path for the series resonant circuit L1, C3 or L2, C4, which determines the frequency of the range mark pulses. Transformer T1 differentiates the output waveform of Q3 before it is applied to Q4, which serves as an emitter follower stage. C1 is the input coupling capacitor, and R1 establishes the contact bias for Q1. Resistor R2 is a collector voltage



228.143

Figure 3-12.—Range marker generator.

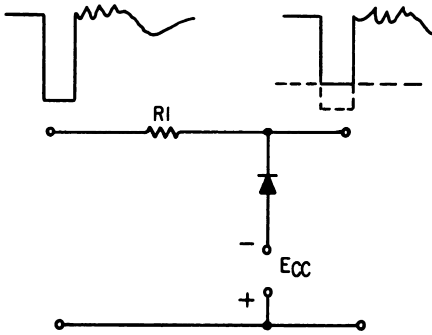
dropping resistor to provide Q1 with a lower potential than the collector voltage value of Q2. R4 is a common collector load resistor for Q1 and Q2. R3 places the emitter of Q1 at a less positive potential than the emitter of Q2. R5 holds the base of Q2 at approximately zero bias. R6 serves as a return to ground for the base of Q2, and C2 places the base of Q2 at an ac ground potential. R7 places the emitter of Q2 at some less positive potential than the emitter of Q3. Resistor R8 is part of an emitter bias voltage divider on the emitter of Q3. The divider consists of R3, R7, and R8, which places different fixed bias on the emitters of Q1, Q2, and Q3 respectively. The primary of T1 serves as a collector load for Q3. Capacitor C5 couples the differentiated waveform to the base of emitter follower Q4. R11 and R9 place the base of Q4 at some highly negative potential. R10 provides a dc return to ground for Q4 and, together with R11, forms a bias voltage divider between the negative supply and ground. Resistor R12 is the emitter resistor of Q4 and serves to match the output of the emitter follower.

Prior to the input pulse from the start-stop multivibrator, Q1 is conducting, which keeps the collector voltage at a low value. The low voltage prevents the collector voltage of Q2 from being higher than the base voltage of Q2. This low collector voltage of Q1 also causes the base of Q3 to be less positive than the emitter, and of sufficient value to keep Q3 cut off. With Q3 cut off, no output signal is developed.

When the negative pulse is applied to Q1, Q1 is cut off. This causes the collector voltage to increase, and this increase causes Q2 and Q3 to conduct. Q3 completes the circuit containing Q3, and the series resonant circuit of L1, C3 or L2, C4, transistor Q2, and the primary of T1. A pulse-type waveform is produced by this circuit with a frequency dependent on the value of the series resonant circuit. The waveform is applied to T1, where it is differentiated by the inductance in conjunction with the resistance of the primary of T1. The output of T1 is coupled via C5 to the base of Q4. The output of Q4 is taken across its emitter resistor R12. The positive output pulses are then applied to the control grid (fig. 3-7) of the CRT to increase the intensity of the trace at the point where the range mark rings (fig. 3-5) are to occur.

The video signal from the radar receiver (which will be discussed later in this chapter) is applied to a biased video limiter. There the signal is made to vary at a specific level so it will not become so negative that it will cause blooming (too bright) on the CRT screen. Figure 3-13 is a schematic of a typical video limiter.

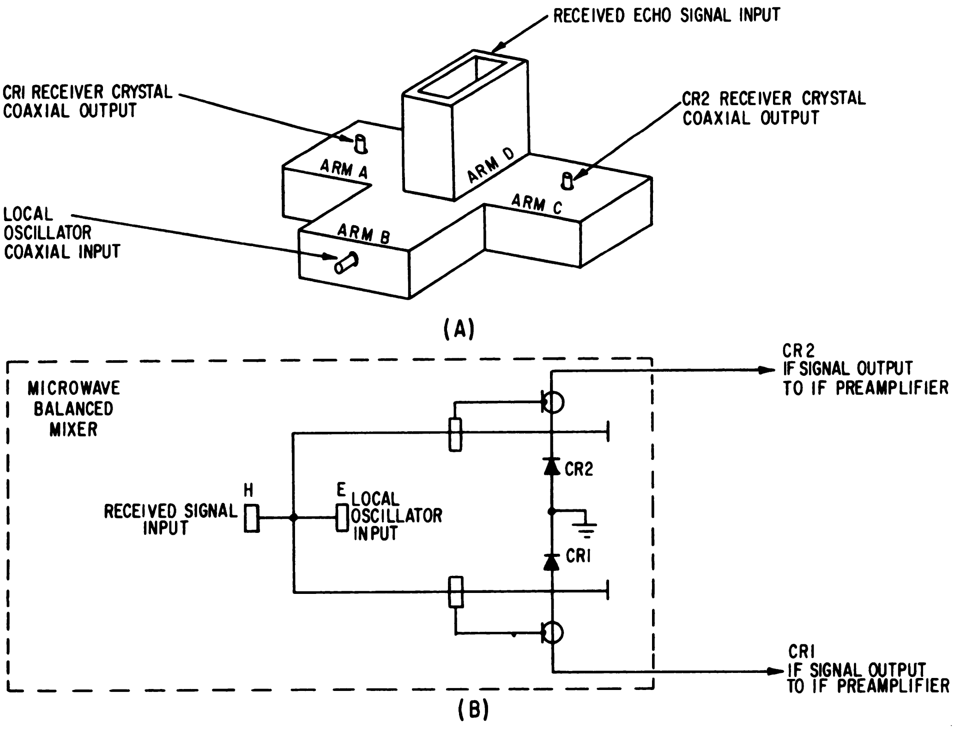
With no signal applied, there will be no signal output. When a positive signal is applied, it will appear at the output unaffected by the limiting diode and the voltage source E_{CC}, since the nonconducting diode acts as an open circuit. Even as the signal begins going negative, the signal will remain unaffected. The negative voltage on the anode of CR1 is greater than the applied negative signal, thereby maintaining CR1 in the nonconducting state. When the signal becomes as negative as E_{CC}, CR1 begins conducting, and the output is now E_{CC}. Even when the input becomes more negative, the output still remains at the value of the source voltage E_{CC}. The output voltage will vary as the input signal only when the input signal becomes more positive than E_{CC}.



228.144

Figure 3-13.—Video limiter.

The output voltage of the video limiter is applied to a video amplifier, or several video amplifiers, where the voltage is increased in gain before being applied to the cathode of the CRT. A typical video amplifier stage will be explained later when we discuss the radar receiver.


RECEIVED ECHO SIGNAL INPUT
CR1 RECEIVER CRYSTAL COAXIAL OUTPUT
CR2 RECEIVER CRYSTAL COAXIAL OUTPUT
LOCAL OSCILLATOR COAXIAL INPUT
ARM A
ARM B
ARM C
ARM D
(A)
MICROWAVE BALANCED MIXER
CR2 IF SIGNAL OUTPUT TO IF PREAMPLIFIER
H
E
RECEIVED SIGNAL INPUT
LOCAL OSCILLATOR INPUT
CR2
CR1
CR1 IF SIGNAL OUTPUT TO IF PREAMPLIFIER
(B)

228.145

Figure 3-14.—A. Waveguide balanced mixer; B. Waveguide balanced mixer schematic diagram.

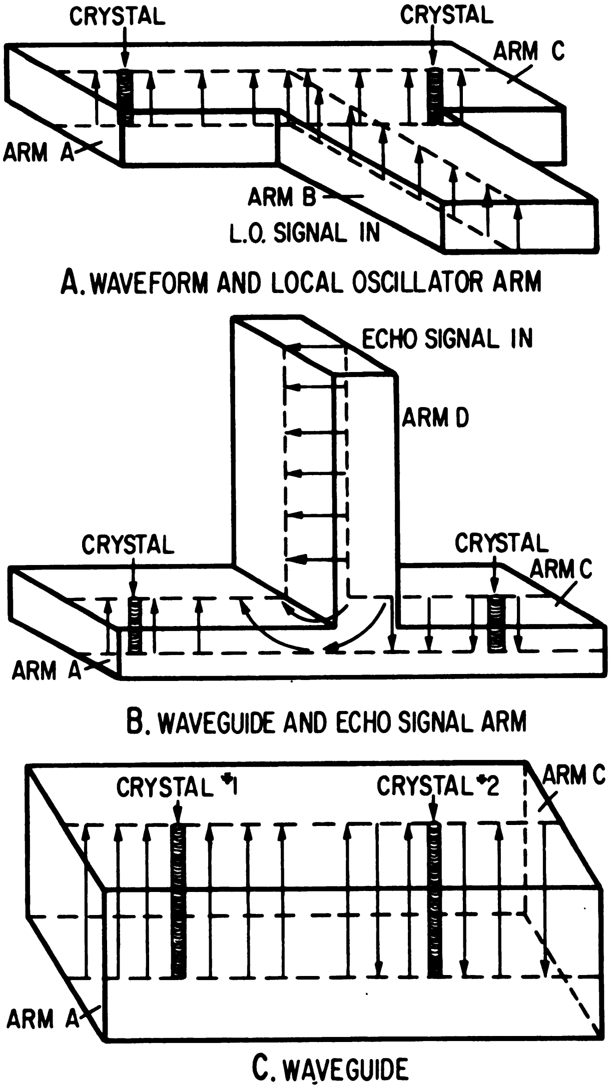
RECEIVER

Because the received RF echo pulses are very small, the radar receiver must have high-gain and low-noise capabilities. As you have already learned, the typical superheterodyne receiver fulfills these requirements. However, due to the noise produced by RF amplifier stages at microwave frequencies, radar receivers are modified slightly. Instead of RF amplifier stages, the typical radar receiver uses a waveguide balanced mixer (microwave mixer), and an IF preamplifier to produce the gain normally achieved by RF amplifier stages, but with much less inherent noise. The rest of the receiver (IF amplifier stages, detector, video amplifier and output stages) are similar to a typical superheterodyne receiver.

MICROWAVE MIXER

The typical radar receiver microwave mixer is a waveguide balanced mixer. (See figure 3-14A & B.) This section of waveguide forms a hybrid junction (also referred to as "hybrid T" or "magic T"). It is a waveguide arrangement with four branches, so constructed that energy (signals) entering one of the four branches is coupled to only two of the three remaining branches. In figure 3-14A the four branches are labeled "ARM A," "ARM B," "ARM C," and "ARM D." The receiver crystals (CR1 and CR2) are inserted directly into the waveguide, and coaxial probes are used to couple the output signals. The crystals are located one-quarter wavelength from their respective short-circuited waveguide ends; that is, the point of maximum voltage along a tuned line. The crystals are also connected to an impedance network located in the IF preamplifier. This network can be adjusted for optimum coupling and best noise figure.

The local oscillator signal is injected into Arm B (fig. 3-14A) by a coaxial probe. The signal is distributed as shown in figure 3-15A. You will note that the local oscillator signal is in phase across the crystals. The received signal is injected into Arm D (fig. 3-14A) by waveguide connection from the antenna. The signal is distributed as shown in figure 3-15B. Note the signal is out of phase across the crystals. The resulting fields are illustrated in figure 3-15C.

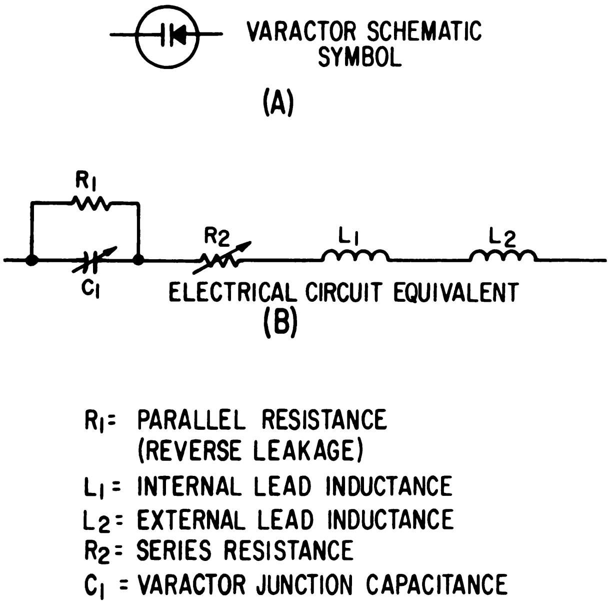


228.146

Figure 3-15.—Balanced mixer fields.

Since there is a difference in phase between the received signals applied across the two crystals, and because the local oscillator signal is in phase across both crystals, there will be a condition when both signals applied to CR1 will be in phase and the signals applied to CR2 will be out of phase. This results in an IF frequency (difference between local oscillator and received signal frequencies) signal of one polarity across

CR1 and of the opposite polarity across CR2. When these two signals are applied to the input circuit of an IF preamplifier, they will add; outputs of the same polarity will cancel each other. It is this action which helps to eliminate inherent local oscillator noise. The IF preamplifier will be discussed later in this chapter.


VARACTOR SCHEMATIC SYMBOL
(A)
R1
R2
L1
L2
C1
ELECTRICAL CIRCUIT EQUIVALENT
(B)
R1 = PARALLEL RESISTANCE (REVERSE LEAKAGE)
L1 = INTERNAL LEAD INDUCTANCE
L2 = EXTERNAL LEAD INDUCTANCE
R2 = SERIES RESISTANCE
C1 = VARACTOR JUNCTION CAPACITANCE

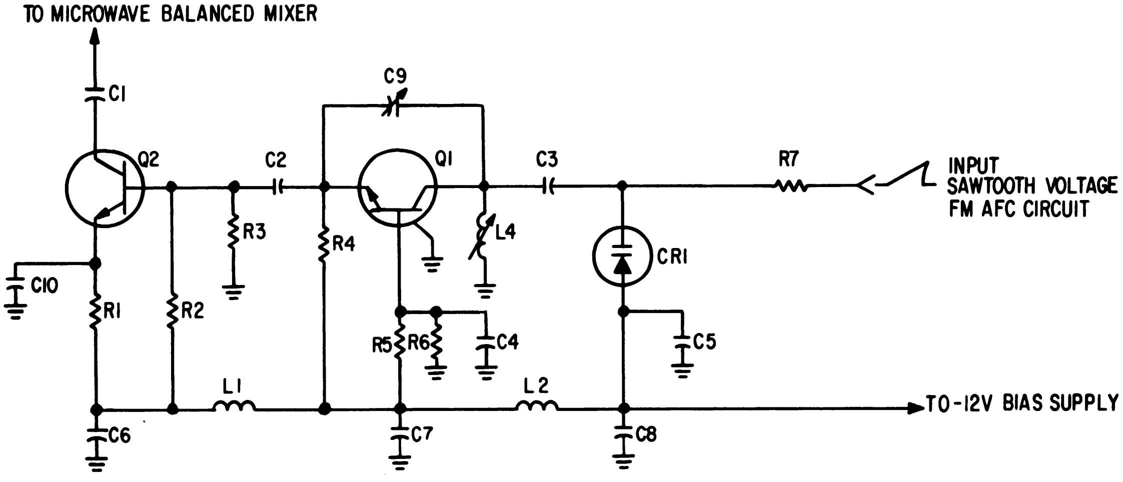
228.147

Figure 3-16.—Equivalent circuit for a varactor diode at microwave freqnencies.

LOCAL OSCILLATOR

For years, the local oscillator used in practically all microwave radar systems was the reflex klystron. With the advent of solid state devices and particularly the varactor, it became possible to design more efficient oscillator circuits. Most modern radars today use solid state, variable frequency, voltage controlled, varactor oscillators.

As explained in *Basic Electronics, Volume 1*, NAVPERS 10087 (Series), the varactor diode is a semiconductor device that is employed as a variable reactance circuit element, with the variable reactance being provided by the P-N junction capacitance, which varies as a function of the voltage applied to it. The varactor operates principally between a very small positive bias and the reverse breakdown voltage. Under these conditions, the varactor shown in figure 3-16A can be represented electrically by the equivalent circuit shown in figure 3-16B. The fact that the junction capacitance can be varied by an applied voltage, and varied sufficiently to provide a useful capacitance change, enables the varactor diode to be used for tuning oscillator tank circuits over a wide frequency range.



228.148

Figure 3-17.—Typical radar varactor voltage-controlled oscillator (VCO) circuit.

Theory of Operation

Figure 3-17 is a diagram of a typical varactor, voltage-controlled, variable-frequency oscillator circuit, used in present radars.

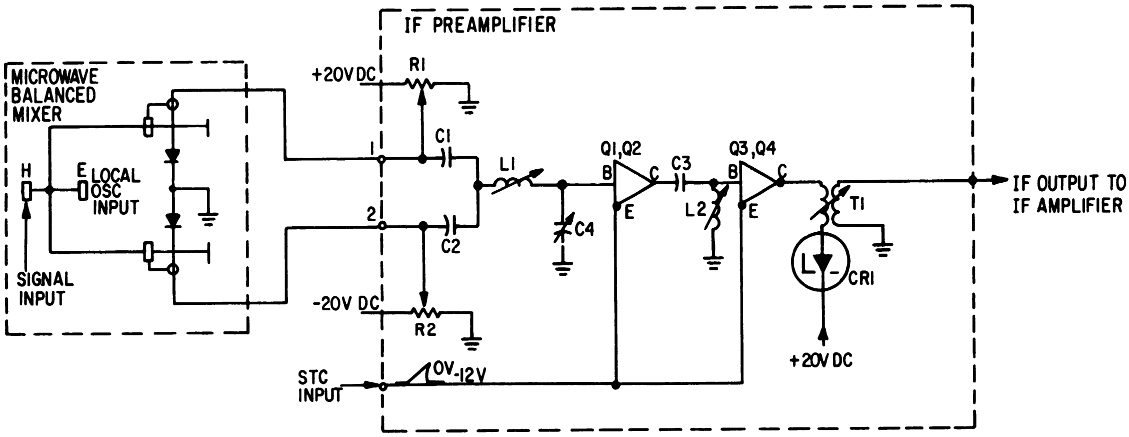
The input sawtooth voltage (developed by an automatic frequency control (AFC) circuit, which will be discussed later in this chapter) is applied across R7 to varactor diode CR1. CR1 is essentially a voltage-sensitive variable capacitor, in series with a semiconductor diode. The diode portion of CR1 is effectively at RF ground, since it is connected to the −12 V bias line and bypassed to ground by capacitor C5. The incoming sawtooth voltage changes the capacity of CR1 P-N junction, which is in parallel with coil L4, forming a resonant tank circuit in the collector circuit of oscillator Q1. Coil L4 is effectively connected from the collector to the base of Q1, due to bypass capacitor C4. The feedback necessary to sustain oscillations is provided by adjustable capacitor C9. Taking into account the RF effects of bypass capacitors C4 and C5 (they effectively place the base of Q1, L4 and CR1 to ground or a common tie), you will note that Q1, CR1, and L4 form a transistor Colpitts oscillator circuit (which was explained in *Basic Electronics, Volume 1*).

The sine wave output signal of Q1 (whose frequency is dependent upon the capacitance of CR1) is applied to the base of Q2. Q2 is a buffer amplifier, whose output is coupled by capacitor C1 to the microwave balanced mixer local oscillator input probe.

IF PREAMPLIFIER

The typical radar IF preamplifier is a low-noise, high-gain amplifier, which is tuned to the receiver's IF frequency (normally in the range of 60 MHz). Figure 3-18 is a functional signal flow diagram of a typical IF preamplifier, showing its connection to a microwave balanced mixer. Figure 3-19 is a simplified schematic of the IF preamplifier with only those components labeled which appear in figure 3-18. Refer to these figures during the following discussion.

The input from the balanced mixer (received signal at the IF frequency) is coupled across C1 and C2, through L1 to the base of Q1. R1 and R2 adjust the bias of the balanced mixer crystals at the best noise figure. L1 and C4 form an impedance matching network which is also adjusted for the best noise figure. Q1 and Q2 form a high gain, cascode amplifier. The output of Q2 is taken off the collector, coupled across C3 to the bases of Q3 and Q4. Q3 and Q4 are parallel amplifiers which provide the necessary signal power without gain compression. L2 tunes the center frequency of the amplifier and T1 adjusts the amplifier's bandwidth and gain figure. The output signal is coupled across T1



228.149

Figure 3-18.—Typical IF preamplifier functional signal flow diagram.

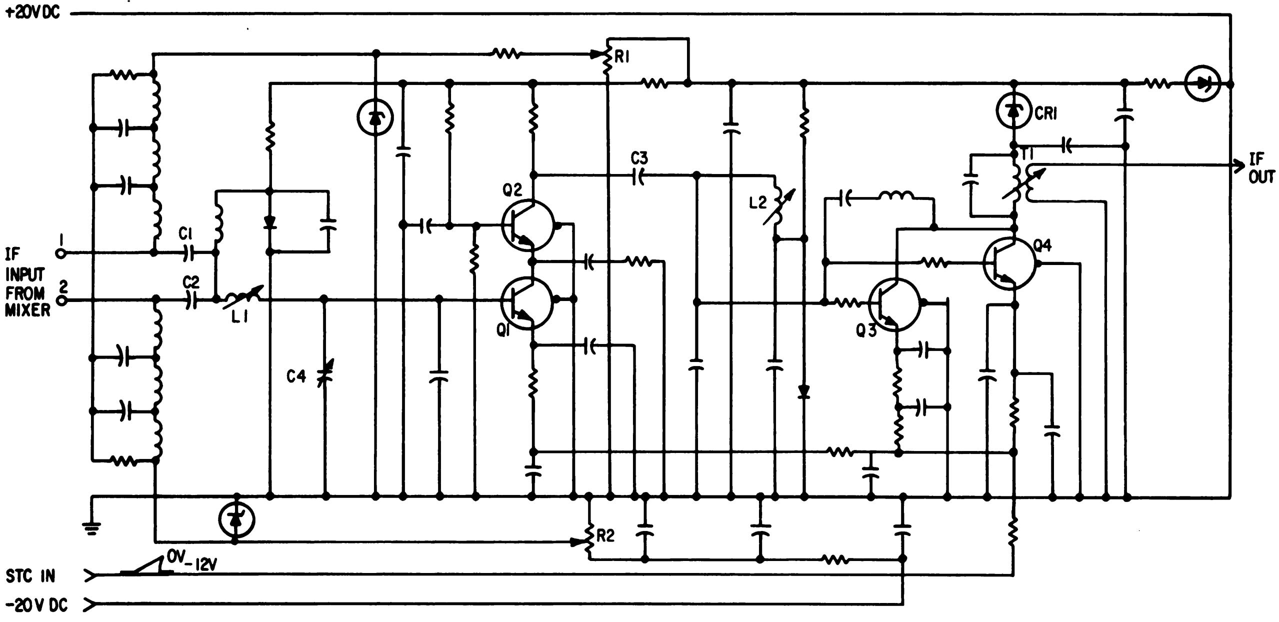


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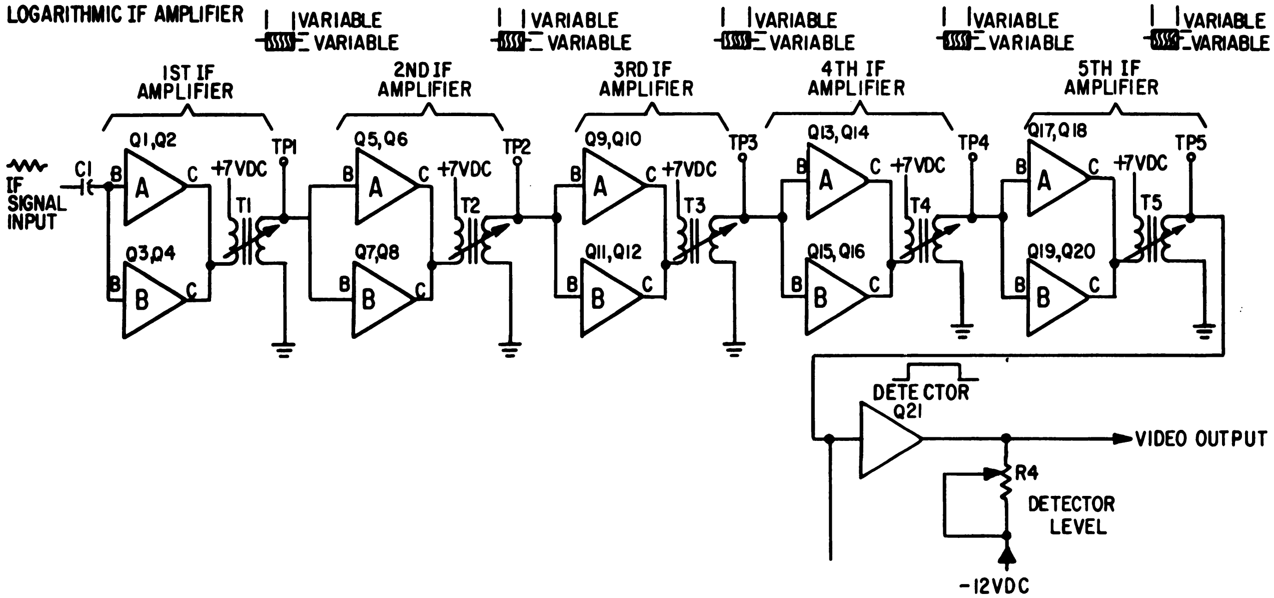
Figure 3-19.—Typical IF preamplifier simplified schematic.



228.151

Figure 3-20.—Logarithmic IF amplifier functional signal flow diagram.

and is the input to the receiver's IF amplifier stages. The rest of the unlabeled components establish biasing, and the like, for the amplifier. The STC (sensitivity time control) input controls the gain of the preamplifier to prevent saturation of the display indicator by large nearby ground clutter targets. This input is a negative going ramp voltage from an STC circuit, consisting of a monostable multivibrator, a charging RC network and a driver amplifier. The resistance of the RC network is controlled by an adjustable pot located on the radar's control panel, which the operator adjusts for best picture. By adjusting the RC time, both the ramp duration and amplitude can be set, which lowers the gain of the preamplifier for a period of the receive time. This period is usually from 0 to 20 miles on the indicator. This voltage is applied to the emitters of Q1, Q3, and Q4 and controls the gain of these stages by controlling the emitter-base bias. The more STC adjusted in by the operator, the less negative voltage is applied to the emitters during STC time, thus decreasing the amplification factor.

IF AMPLIFIERS

At this point you might want to review microwave receivers in *Basic Electronics, Volume 2*, as an aid to your understanding of IF amplifier operation. Radar receiver IF amplifiers require high gain to amplify the input signal to the level required to operate the detector. Many different circuit arrangements are used to achieve this required gain. One circuit arrangement which is increasing in use is the logarithmic amplifier. This type of amplifier stage produces high gain while maintaining the resonant frequency and bandpass of the tuned coupling circuits fairly constant over the dynamic range of the input signal. The output of a logarithmic amplifier is a logarithmic (as opposed to linear) function of its input signal.

Figure 3-20 is a functional signal flow diagram of a typical logarithmic IF amplifier. Figure 3-21 is a schematic diagram of the first IF amplifier stage shown in figure 3-20. All of the IF amplifier stages (1st through 5th) are identical. Refer to figures 3-20 and 3-21 during the following discussion.

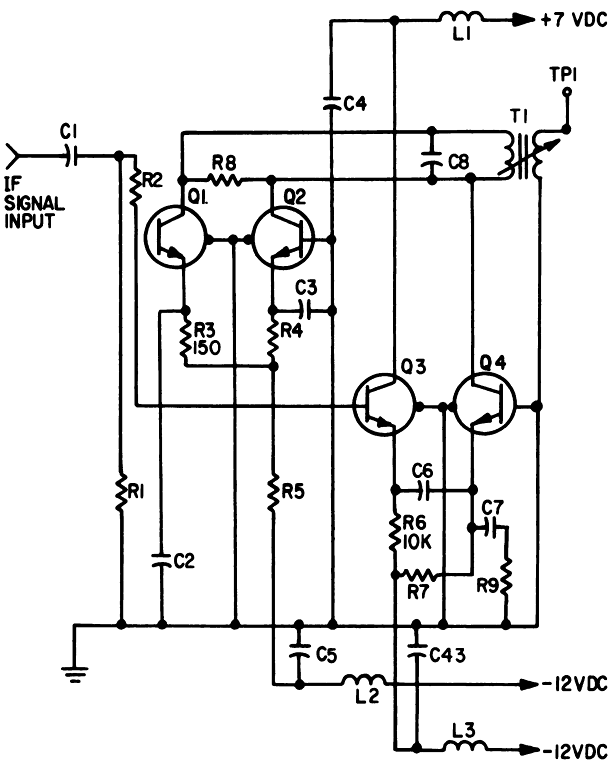


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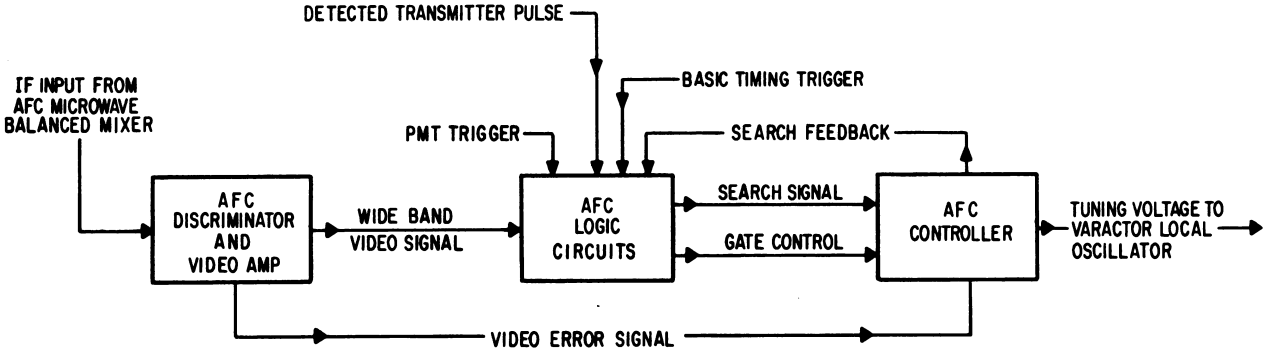
Figure 3-21.—Typical IF logarithmic amplifier stage schematic diagram.

The IF input signal (from the IF preamplifier) is coupled across C1 to the bases of the A and B amplifiers. These amplifiers are in parallel across the output coupling transformers. The A amplifier consists of Q1 and Q2 and the B amplifier consists of Q3 and Q4. Both the A and B amplifiers are single-ended differential amplifiers.

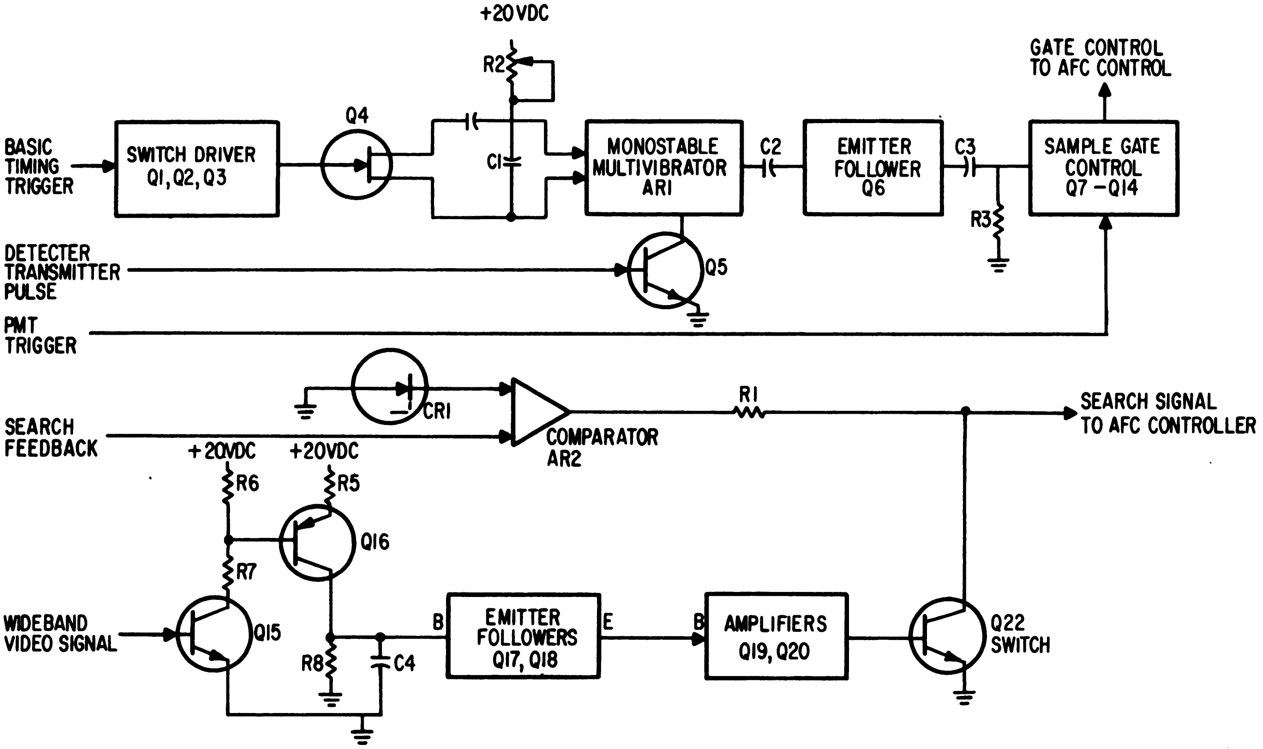
The A amplifier (Q1 and Q2) has a constant gain of approximate unity as determined by R3 and R4. Since there is no load resistor for Q1, the collector bias supply filter capacitor (located in the +7 V dc power supply) effectively grounds the collector for ac signals. The output of Q1 is taken off its emitter and applied through R3 and R4 to the emitter of Q2. The output of Q2 is taken off its collector and applied to T1, the interstage transformer coupler. T1 and C8 form a tuned tank, which is tuned to the IF frequency.

The B amplifier (which is in parallel with the A amplifier) has a high gain for weak signals, but is quickly limited as the input signal strength increases. When Q3 conducts (in the same manner as Q1), the output signal is taken off its emitter at the top of R6. The signal is coupled across C6 to the emitter of Q4. Q4 is so biased, that it will cut off before Q3 reaches saturation. The weaker the input signal, the more Q4 will conduct and aid the output of Q2. The output of Q4 is taken off its collector and is applied to T1 along with the output of Q2. Since Q2 and Q4 are in parallel, feeding a common load, as the input signal increases, the high-gain stage quickly decreases



228.153

Figure 3-22.—AFC circuits simplified block diagram.



228.154

Figure 3-23.—AFC logic circuit functional signal flow diagram.

toward unity. This closely approximates a logarithmic response. By cascading amplifiers (1st through 5th) a large dynamic input range is attained. The output is detected after the last (5th) stage and goes to the video amplifier stages.

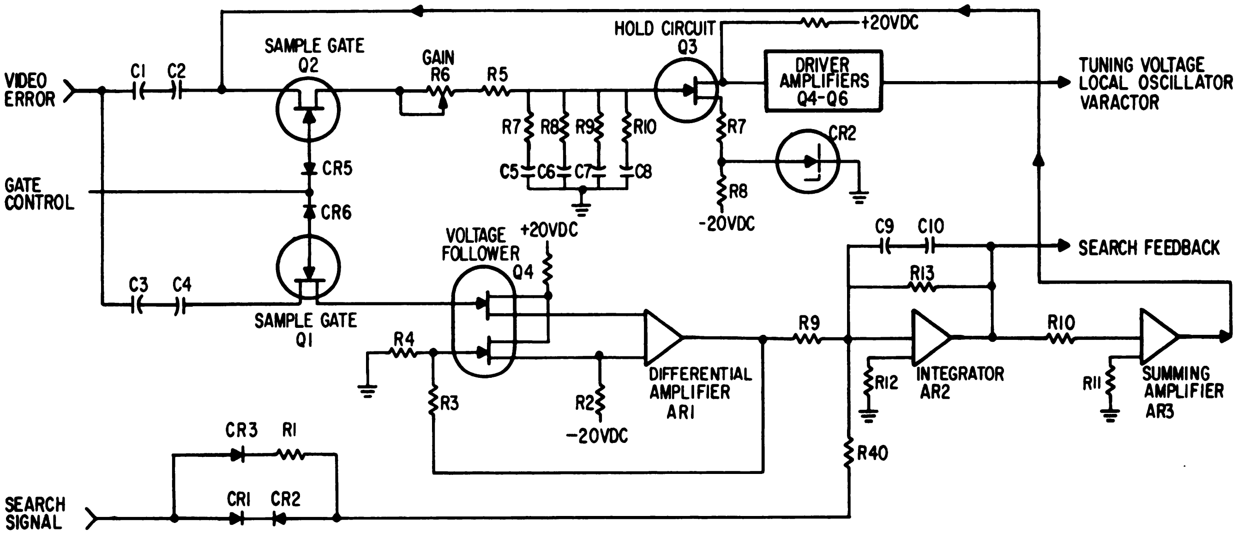
AUTOMATIC FREQUENCY CONTROL (AFC) CIRCUITS

The purpose of the radar receiver's AFC circuits is to tune the receiver local oscillator to the correct operating frequency. In order for the receiver to process the received signal, the local oscillator must be tuned to the proper frequency so that the IF frequency output of the receiver's balanced mixer (difference frequency of the local oscillator and received signal) is correct. To ensure this, the local oscillator must be tuned during transmit time (prior to the reception of a return pulse). To accomplish this, the AFC circuits utilize another microwave balanced mixer similar to the receiver's balanced mixer in figure 3-14B. The inputs to this mixer are the receiver local oscillator and an attenuated sampled transmitted pulse. The output IF frequency would be the same as the receiver balanced mixer. (The received signal is the transmitter pulse reflected off a target.) The output of the AFC microwave balanced mixer goes to the receiver's AFC circuits. Figure 3-22 is a simplified block diagram of a typical AFC circuit. Refer to this figure during the following discussion.

There are three basic steps or modes of operation utilized by the AFC circuits to tune the local oscillator to the correct frequency. They are referred to as "search," "acquisition," and "loop control" modes.

Search Mode

The AFC circuits go into a search mode any time the local oscillator is so far off frequency that the IF frequency produced by the balanced mixer (difference frequency of local oscillator and transmitter frequency) is outside the limits of the receiver's IF tuned circuits and cannot be processed. An IF preamplifier contained in the AFC discriminator is tuned to the receiver's IF frequency. Therefore, if the IF input to the discriminator is beyond the receiver's bandpass limits (usually plus or minus 10 MHz), the signal will not be processed by the AFC discriminator. When this occurs, there are no output signals out of the discriminator to either the AFC logic circuits or the AFC controller circuits. Instead, a comparator (fig. 3-23) AR2 part of (p/o) the AFC logic circuit gets an input (search feedback) from an integrator (fig. 3-24) AR2 p/o the AFC



228.155

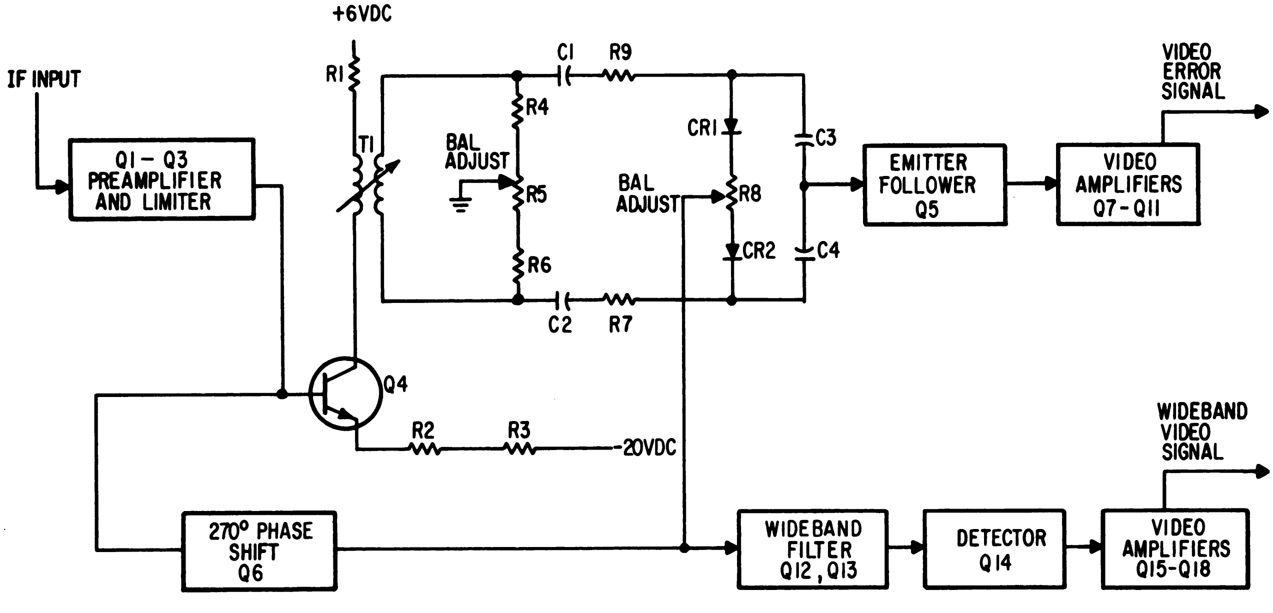
Figure 3-24.—AFC controller functional signal flow diagram.

controller circuit. This input may be either positive or negative depending on the output state of the integrator. The output of the comparator (fig. 3-23) is coupled through R1, bypasses switch Q22 (which is cut off as there is no wideband video signal input from the discriminator), and goes to CR1 and CR3 (fig. 3-24) of the AFC controller. Depending on the polarity of the comparator output, the output goes through either CR1 and CR2, or CR3 and R1, to the integrator AR2. The gain of the integrator is different for the different polarities of the comparator output. This results in a sawtooth output voltage from the integrator AR2. The sawtooth voltage goes through the summing amplifier AR3 and is also fed back to the comparator AR2, (fig. 3-23) which causes it to change states when a certain voltage level is reached. The output of the summing amplifier AR3 is applied to the sample gate Q2 (N-channel JFET). The gate Q2 is open at this time. (This will be explained when we cover the sample gate control p/o the AFC logic circuit.) The sawtooth goes through Q2, across a hold charging circuit consisting of R7, 8, 9, and 10; and C5, 6, 7, and 8, through gate Q3, is amplified by drivers Q4 through Q6 and is applied to the receiver local oscillator varactor. The amplitude of the sawtooth will cause the local oscillator to sweep through its entire operating range. It is also large enough to overcome the hold circuit.

When the local oscillator reaches a frequency where, when it is mixed with the sampled transmitted pulse in the microwave mixer, and an IF frequency is produced within the IF bandpass of the receiver (±10 MHz), the IF signal will be processed by the AFC discriminator circuits. At this point, acquisition has occurred.

Acquisition Mode

Once the AFC mixer's IF frequency output is within the ±10 MHz bandpass of the AFC discriminator's preamplifier, the input to the discriminator (fig. 3-25) will be amplified/limited (depending on signal amplitude) by Q1 through Q3. The output of Q3 is fed via Q4 to the discriminator circuit consisting of T1, R4, R5, R6, C1, C2, R7, R8, R9, CR1, CR2, C3, and C4. The output of Q3 is also fed to Q6. The circuitry of Q6 phase shifts the output (delays the signal) by 270°. The output of Q6 is applied



228.156

Figure 3-25.—AFC discriminator and video amplifier functional signal flow diagram.

between CR1 and CR2 and is the reference signal for the discriminator. The output of Q6 is also applied to wideband filter Q12 and Q13.

The operation of the discriminator is similar to the Foster-Seeley discriminator explained in *Basic Electronics, Volume 1*. It is basically a phase detector with the output rectified and filtered. The output of the discriminator is a pulse, the width of the transmitter pulse, that has an amplitude and polarity which is determined by the frequency difference between the local oscillator and the sampled transmit pulse. This output is amplified by Q7 through Q11 and is the video error signal, which is applied to C1 and C3 (fig. 3-24) of the AFC controller.

The output of the wideband filter Q12 and Q13 (fig. 3-25) is detected by Q14, amplified by Q15 through Q18, and is the wideband video signal, which is applied to Q15 (fig. 3-23) of the AFC logic circuit.

The wideband video signal causes Q15 and Q16 to conduct, which charges C4. When the charge on C4 reaches a predetermined value, the signal is coupled by Q17 and Q18 to amplifiers Q19 and Q20, and turns on switch Q22. Q22 clamps the output of the comparator AR2, and also clamps the feedback circuit (fig. 3-24) of the integrator AR2 p/o the AFC controller. The integrator will no longer generate the (search) sawtooth voltage to the local oscillator. At this point, the search mode is terminated, acquisition is complete, and tracking (loop-control mode) begins.

Loop-Control Mode

There are actually two paths or loops comprising the loop-control mode. One is commonly referred to as "slow loop," which corrects the oscillator frequency from ±10 MHz to within ±5 MHz of the desired IF center frequency. The second path is referred to as the "fast loop" and will correct the oscillator frequency from ±5 MHz to the correct frequency.

SLOW-LOOP OPERATION.—The video error signal (fig. 3-24) which was the output of the discriminator (beginning at acquisition) is applied to C1 and C3. C1 is the fast-loop circuit, which is ineffective when the local oscillator frequency error exceeds ±5 MHz. (We'll see why shortly.) The video error signal is coupled across C3 and C4 to sample gate Q1. Q1, just as Q2 in search, is open at this time. (We'll explain how when we discuss the sample gate control later in this chapter.) The signal passes through gate Q1 to Q4. Q4 and AR1 operate as a voltage follower circuit. The output of AR1 is integrated by AR2, amplified by AR3, and applied across the opened sample gate Q2 to the hold circuit. Slow-loop operation can be summarized as follows: So long as the oscillator frequency error exceeds ±5 MHz, then the slow-loop circuit takes a series of video error signal samples, and integrates them until a sufficient voltage level is reached to charge the hold circuit to open gate Q3 and drive the local oscillator frequency to within ±5 MHz of the desired frequency. Once this is accomplished, fast-loop operation begins.

FAST-LOOP OPERATION.—The video error-signal output of the discriminator will now be coupled across C1 and C2 to the sample gate Q2. The sample gate at this time will open periodically as determined by the sample gate control circuits p/o the AFC logic circuit. When gate Q2 opens, the video error signal goes to the hold circuit of Q3. The hold circuit, which was charged by the slow-loop circuits, is at the threshold voltage level to turn on Q3. The error signal amplitude is sufficient to turn on Q3 and send a short voltage burst to the local oscillator varactor to tune the oscillator to the desired frequency. Once the desired frequency is reached, there will no longer be a video error-signal output from the discriminator and no further tuning of the local oscillator. Should the transmitter frequency or local oscillator frequency drift slightly, a video error-signal output from the discriminator would again go through the fast loop circuits and retune the local oscillator. In this manner the AFC circuits maintain the desired IF frequency output of the receiver's balanced mixer.

Sample Gating Operation

The sample gates, Q1 and Q2 (fig. 3-24), are initially opened by a pre-master trigger (PMT) (fig. 3-23) being applied to the sample gate control circuits Q7 through Q14. Prior to receiving the PMT trigger, the output of Q14 is a highly negative (approximately −15 V dc) voltage, which, applied across (fig. 3-24) CR5 and CR6, causes the N-channel gate to be closed. The STO trigger is a pulse from the radar synchronizer and occurs a few microseconds prior to the basic timing pulse, which fires the transmitter and the scope sweep circuits, etc. This ensures the sample gate is opened prior to any possible output from the receiver or AFC balanced mixers. (The output of the balanced mixers is the difference frequency of the local oscillator and sampled transmitter pulse.) The gates Q1 and Q2 (fig. 3-24) will close (fig. 3-23) with the detected transmit pulse being applied to Q5. This pulse triggers a monostable multivibrator, AR1. The negative pulse output of AR1 causes the sample gate control Q7 through Q14 to turn off (close) the sample gates Q1 and Q2 (fig. 3-24). The multivibrator will generate different negative output pulses depending on the prf of the radar. Since a typical radar is normally capable of operating at two different prf's and pulse widths for long- and short-range operation, the basic timing pulse (fig. 3-23) is applied to switch drivers Q1 through Q3. The output of the switch drivers opens and closes gate Q4, which changes (determines) the time constant of AR1. Therefore, sample gates Q1 and Q2 (fig. 3-24) will be open for different periods of time depending on the prf of the radar. However, the overall time the sample gates are opened is from the PMT trigger time to the time of the detected transmitter pulse. The time constant of the monostable multivibrator is such that gates Q1 and Q2 (fig. 3-24) will close just prior to the trailing edge of the transmitted pulse. This is to ensure that the AFC circuits will not inadvertently tune the receiver local oscillator during the receive cycle of the radar operation.

VIDEO AMPLIFIER

Video amplifier stages are similar to the superheterodyne receiver audio amplifier stages previously discussed. However, since the video amplifier must provide uniform amplification at a higher frequency, as well as cover a broader frequency response, certain circuit modifications are required. Figure 3-26 is a schematic of a typical video amplifier stage. Note that except for inductors L1, L2, L3, and capacitor C3, the circuit is the same as an audio amplifier stage. It is these components that form the video amplifier.

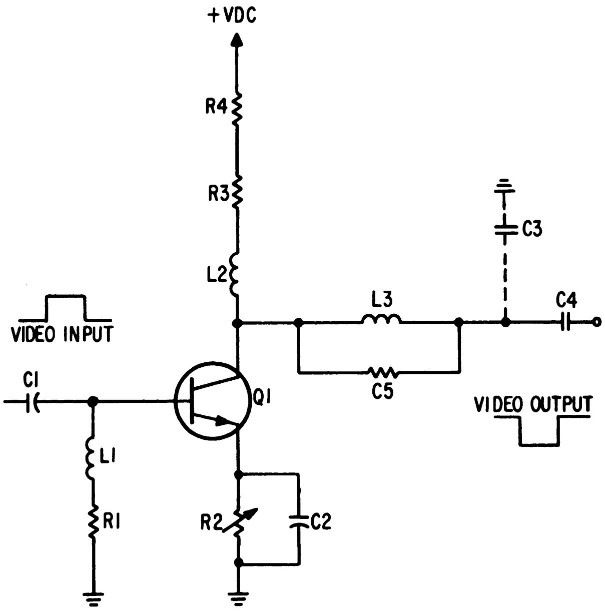


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Figure 3-26.—Typical video amplifier stage.

Inductor L3 is a series peaking coil, which functions as a series filter for passing required frequencies. It also isolates circuits preceding it from circuits following it. Resistor R5 aids L3 by extending the effects of L3 and broadening the Q characteristics. Inductors L1 and L2 are shunt peaking coils that form a parallel resonant circuit with the distributed capacitance (C3) which occurs at high frequencies. These resonant circuits provide a high impedance for the video signal, so that none of the frequency components of the signal are shunted to ground by the circuit distributed capacitance. Aside from the actions of L1, L2, L3, and C3, the amplifier stage operates the same as an audio amplifier stage. This type of video amplifier stage is used in both the radar receiver and the radar indicator.

IFF

With the destructive power of modern weapon systems and the speed of modern weapon delivery systems, it is not practical to wait until a detected radar target is identified by visual means before preparing for battle. Therefore a means of identifying friendly targets from enemy targets at long range is required. It was this need that brought about the advent of IFF. The IFF system permits a friendly craft to identify itself automatically (by means of an IFF transponder) when interrogated (by means of an IFF interrogator), by either a ground station or another craft. The average operating range of IFF is in excess of 300 miles.

Additionally, due to the high density of air traffic, a special operating mode of the IFF enables an aircraft to identify itself (by special codes) to ground stations equipped with an Air Traffic Control Radar Beacon System (ATCRBS). Still another IFF mode of operation enables an aircraft to automatically report its altitude to an ATCRBS ground station.

IFF SYSTEM

A typical IFF system is shown in figure 3-27. It consists of an interrogator unit, a coder synchronizer unit, a search radar unit, and a transponder unit. The interrogator, synchronizer, and radar units comprise the challenging station, and the transponder unit is the responder station. It should be noted that the challenging station can be a ground station, a ship, or another aircraft. The responder station is normally an aircraft.

Interrogation (Challenge)

The interrogator is a pulse-type transmitter, which is triggered by the coder synchronizer. The coder synchronizer is synchronized to the radar system (IFF challenges are transmitted 1 to 40 μsec after the radar transmitter pulse depending on the particular system) so that reception of the IFF response and radar echo signals cannot occur simultaneously. The output (challenge signal) of the interrogator is different for different modes of IFF operation. (These modes will be explained later in this chapter.) As

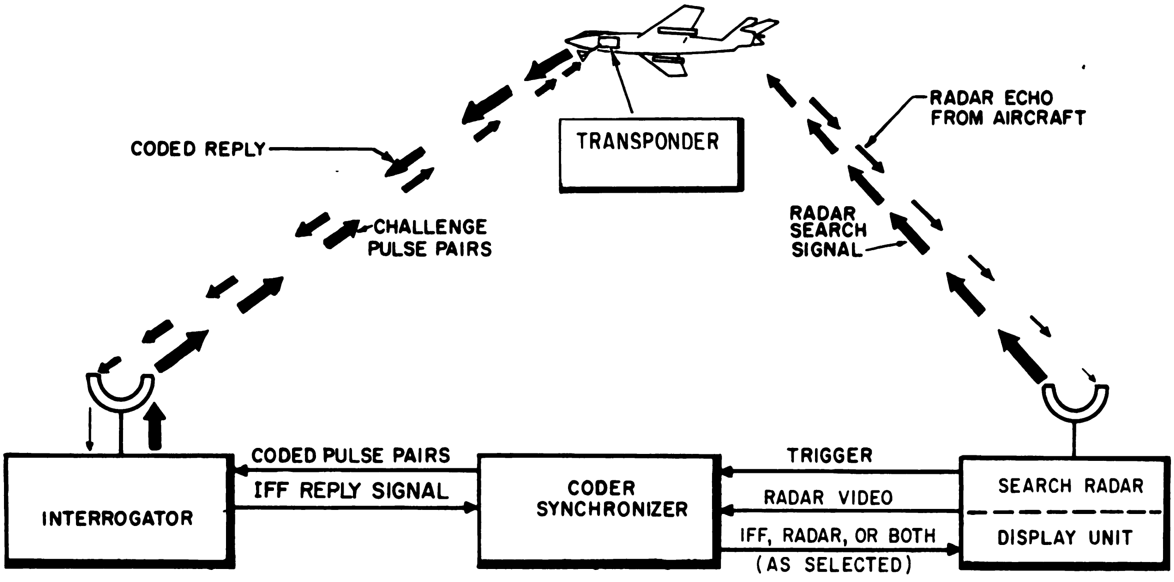

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Figure 3-27.—IFF system block diagram.

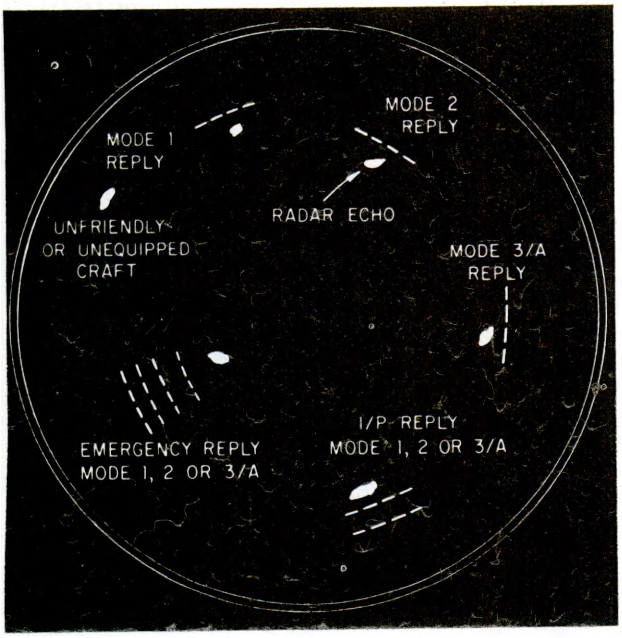

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Figure 3-28.—Typical radar PPI composite display showing several IFF responses.

long as the aircraft transponder is operating in the correct mode, it will receive these interrogation signals and will transmit back to the interrogator the proper coded reply pulses. The IFF reply pulses (fig. 3-27) are sent via the coder synchronizer to the radar PPI indicator. These reply pulses will appear as dashed lines just behind the aircraft target on the scope. Figure 3-28 shows how these reply signals would appear.

INTERROGATION MODES AND CODES.—There are presently five modes of IFF operation used by ATCRBS and naval aircraft. They are designated Mode 1, Mode 2, Mode 3/A, Mode C, and Mode 4. In addition, there is a test mode of operation used only by the aircraft transponder, as a self-check of the transponder equipment.

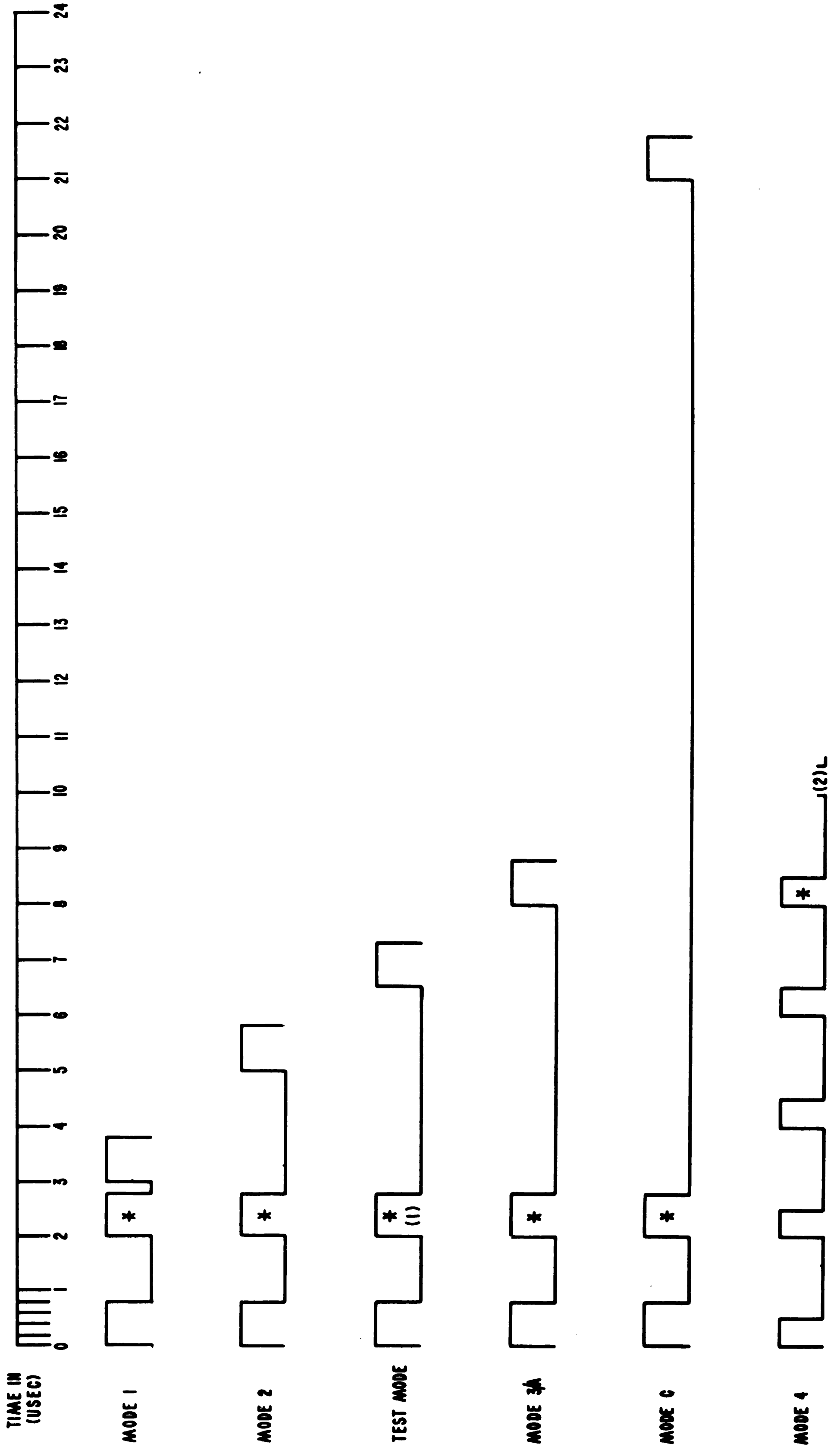
Modes 1 and 2 are for exclusive use by the military as tactical modes for target identification. Mode 3/A is used mainly by military and civilian air traffic control stations. Mode C is used in conjunction with an external pressure altitude digitizer to report the aircraft's altitude to an ATCRBS. Mode 4 is a military encrypted mode, which is controlled by an external computer. The operation of Mode 4 is classified. Only interrogators and transponders using the same encrypted codes can communicate with each other.

INTERROGATION PULSE CHARACTERISTICS.—The interrogation pulse characteristics for the various modes of IFF operation are shown in figure 3-29. These pulses are transmitted at a frequency of 1030 MHz, and are recognized by the transponder through pulse width and spacing. Modes 1, 2, 3/A, C, and test, each use two interrogation and one side-lobe suppression (SLS) pulse 0.8 μsec wide. The pulse spacing is different for each mode of operation. Note (fig. 3-29) the pulse spacing for Modes 1, 2, 3/A, C, and test are 3, 5, 8, 21, and 7 μsec respectively. The side lobe suppression pulse occurs 2 μsec after the leading edge of the first interrogation pulse in each case. The SLS pulse is utilized by the transponder receiver circuits to prevent jamming of the IFF system and to suppress the receiver during operation of TACAN, or other L Band equipment operating in the vicinity of the transponder.

Mode 4 interrogation pulses consist of four pulses 0.5 μsec wide referenced from the leading edge of the first pulse, in multiples of two. (This is determined by the external equipment used to encrypt Mode 4.) The four pulses may be followed by as many as 32 additional pulses spaced as close as 2 μsec apart. The SLS pulse for Mode 4 is spaced 8 μsec from the leading edge of the first interrogation pulse used.

Transponder (Reply)

In the early days of IFF, the transponder of the aircraft being interrogated would receive the interrogation pulses (either 3, 5, or 8 μsec spacing depending on mode of operation), and would automatically respond with reply pulses of the same spacing. But with the increase of air traffic, a more positive means of identification was required. This brought about the advent of the Selective Identification Feature (SIF). This feature has led to the common usage of the designation IFF/SIF system, instead of just the



*-SIDE LOBE SUPPRESSION PULSE (SLS).

(1)-NOT PRESENT WHEN TESTING WITH SIMULATED INPUT.

(2)-SLS PULSE MAY BE FOLLOWED BY AS MANY AS 32 PULSES, SPACED AT 2 USEC INTERVALS.

228.158

Figure 3-29.—IFF interrogator pulse characteristics.

nomenclature IFF system. With the present IFF/SIF system, there are 32 separate reply codes which can be transmitted on Mode 1, and 4096 separate reply codes which can be transmitted on Mode 2 and on Mode 3/A. Mode C has 1024 separate reply codes available.

TRANSPONDER CONTROL PANEL.—The operation of the interrogated aircraft's transponder (mode of operation and specific codes, etc.) is controlled by a control panel similar to the one shown in figure 3-30A, which is normally located on the pilot's control panel. (Refer to fig. 3-30A.)

MASTER Control Switch.—The MASTER control switch is a five-position rotary switch placarded OFF, STBY, LOW, NORM, and EMER. In the STBY position, power is applied to the IFF coder, but interrogations are blocked. In the LOW position, the IFF coder is operational, but the receiver sensitivity is reduced. In the NORM position, the IFF coder is fully operational at normal receiver sensitivity. In the EMER position, the IFF coder transmits emergency replies to interrogations in Modes 1, 2, or 3/A. The Mode 3/A emergency reply includes code 7700. With EMER selected, Mode 4 is enabled regardless of the position of the Mode 4 switch, and Mode C continues to function normally if selected. To select the EMER position, the control is pulled outward and rotated to the EMER position.

IDENT/OUT/MIC Switch.—The IDENT/OUT/MIC switch is a three-position toggle switch. Momentarily actuated (the switch has spring-loaded return) to the IDENT position, the IFF coder adds an identification of position response to Modes 1, 2, and 3/A, for 15 to 30 seconds. In the MIC position, the identification of position function is activated for 15 to 30 seconds whenever the microphone switch is actuated. In the OUT position, the IDENT reply is disabled.

Mode 1-3/A Code Selectors.—Six code-selector switches are provided for selection of Mode 1 and Mode 3 codes. Mode 1 has two thumbwheel selectors which allow selection of 32 different codes. Mode 3 has four thumbwheel selectors that provide the capacity of selecting 4096 codes.

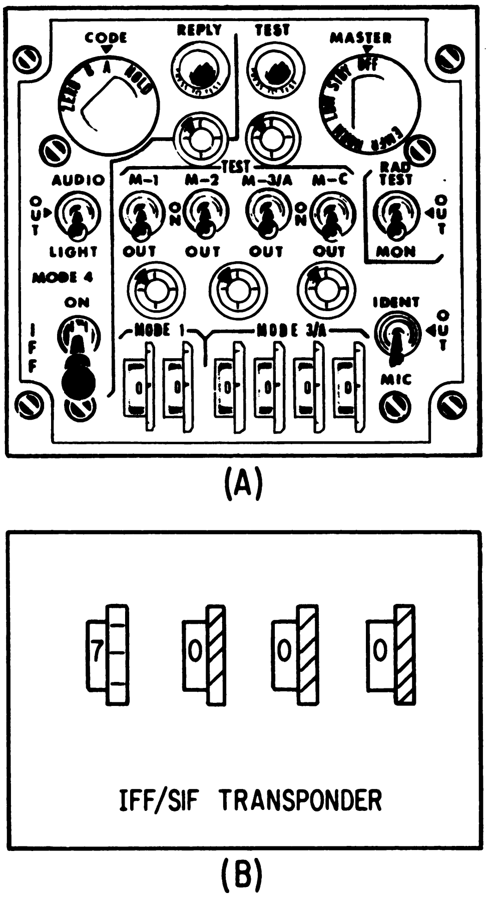


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Figure 3-30.—A. Typical IFF/SIF transponder control box; B. IFF/SIF transponder front panel Mode 2 control dials.

Mode-Selector Test Switches and Light.—Four mode-selector/test-selector switches labeled "M-1," "M-2," "M-3/A," and "M-C" have TEST, ON, and OUT positions. In the momentary TEST position with the MASTER switch at NORM, lighting of the TEST light indicates proper operation of the mode selected. The mode switches for the modes not being tested should be OUT when testing on the ground to prevent unnecessary interference with nearby ground stations.

NOTE

The TEST light may flash once as each mode switch is released from TEST, and as the RAD TEST/MON switch is moved. This flash has no significance.

The OUT position for each switch disables its respective mode. The ON position for each switch enables the transponder to reply to interrogations for the mode selected. The M-C switch provides automatic coded altitude reporting in response to a ground station's interrogation for air-traffic control identification.

RAD TEST/MON Switch.—The RAD TEST/MON switch is a three-position toggle switch spring-loaded to the OUT (center) position. When MON is selected, the TEST light comes on for three seconds each time an acceptable response is made to an interrogation in Modes 1, 2, 3/A, and C. When RAD TEST is selected, Mode 3/A or 4 responds to TEST mode interrogations from a ramp test set during ground maintenance testing.

Mode 4 Operation.—The Mode 4 controls and indicator light are grouped on the left side of the control panel. The MASTER rotary switch controls transponder operation in Mode 4 as well as in the other modes of operation. Mode 4 will operate normally, when selected, in either the NORM or EMER position, and at reduced receiver sensitivity in the LOW position. The Mode 4 function will be inoperative in either the STBY or OFF position. With the transponder functioning, Mode 4 operation is selected by placing the Mode 4 ON-OUT toggle switch to ON. Placing the switch to OUT disables Mode 4 operation.

The Mode 4 CODE control selects either of the two (A or B) Mode 4 codes. It has two additional positions, HOLD and ZERO. The switch is springloaded to return from HOLD to the A position. At a designated daily time and/or prior to the day's mission, maintenance or operations personnel mechanically set in the Mode 4 code for the present code period in position A, and the code for the succeeding code period in position B, with a single insertion of the KIK-18/TSEC Code Changer Key. Both code settings will automatically zeroize when power is turned off or lost after the landing gear has been retracted (that is, after initial takeoff). The code settings can be retained by activating the HOLD function. This will normally be done after the aircraft has landed (landing gear must be down and locked), and before power is removed from the transponder. Place the Mode 4 CODE control to HOLD, and release. Allow transponder power to remain on for at least 15 seconds, and then turn off. The code setting is now mechanically latched and will be retained when aircraft power is turned off.

NOTE

If power is removed from the transponder less than 15 seconds after selecting HOLD, either by turning the transponder off or by turning off aircraft electrical power, the code setting may not be mechanically latched and will zeroize.

AND

Mode 4 settings should be manually zeroized if the aircraft does not make an initial takeoff (that is, gear was never raised), or if the hold function has been engaged and a subsequent takeoff was not carried out.

With aircraft power on and the MASTER rotary switch in any position except OFF, both code settings can be zeroized at any time by placing the CODE switch to the ZERO position. Both code settings will also be zeroized if the HOLD function has not been properly actuated before the MASTER switch is turned to OFF. (Inadvertent selection of OFF is prevented by switch design, which requires that the rotary knob be pulled out before it can be turned to OFF.) When the CODE switch is placed in the A position, the aircraft transponder will respond to Mode 4 interrogations from an interrogator using the same code setting as that set into the

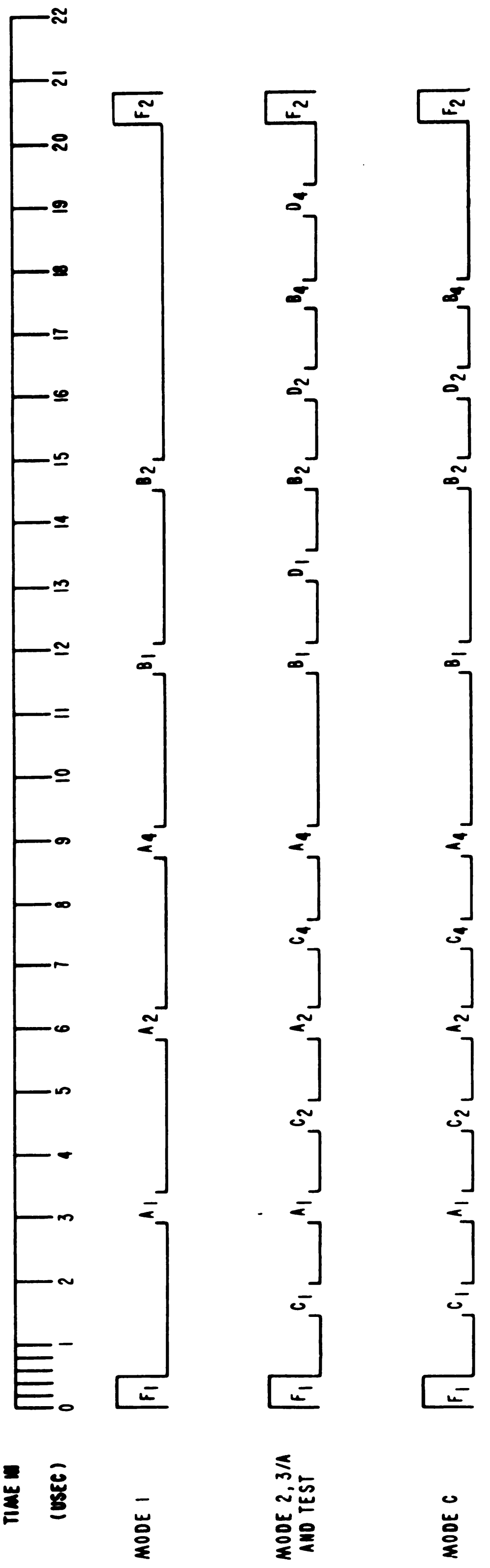

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Figure 3-31.—Normal reply pulse characteristics.

aircraft's code A position. In the B position, interrogations from an interrogator using the same code setting as that set into the aircraft's code B position will be answered. The change-over time from code A to code B use is operationally directed.

The Mode 4 AUDIO-LIGHT switch selects the aircraft indication for Mode 4 replies. In the LIGHT position, the Mode 4 REPLY lamp (green) will light when Mode 4 replies are transmitted. In the AUDIO position, an audio signal in the pilot's headset indicates Mode 4 interrogations are being received, and lighting of the Mode 4 REPLY light indicates when replies are transmitted. Mode 4 audio volume can be adjusted by the appropriate aircraft intercom audio volume control. In the OUT position, both light and audio indications are inoperative.

Mode 2 Code Selectors.—The code control dials (similar to Mode 3/A) for Mode 2 are located on the front of the IFF/SIF transponder as illustrated in figure 3-30B. The Mode 2 reply code setting is usually established and dialed in by the AT prior to flight. As with Mode 3/A, the four thumbwheels provide for 4096 available codes. The Mode 2 reply code normally cannot be changed in flight due to the inaccessibility of the transponder unit.

TRANSPONDER NORMAL REPLY MODES AND CODES.—During IFF/SIF interrogation, the interrogating station will notify the pilot (via UHF or VHF communications) to set the transponder to a specific mode (1, 2, 3/A, and/or C or 4) of operation, to undergo interrogation (identification), and in the case of Modes 1 and 3/A, will direct the pilot to set a specific reply code. (Mode C and Mode 4 codes are automatically controlled by external equipments and Mode 2 is preset.)

Figure 3-31 illustrates the normal reply pulse characteristics of the IFF/SIF transponder. These reply pulses are transmitted at 1090 MHz, between two framing pulses labeled "F1" and "F2." The interrogator transmits on 1030 MHz and receives on 1090 MHz; the transponder receives on 1030 MHz and transmits (replies) on 1090 MHz. Refer to figures 3-30 and 3-31 during the following discussion.

When the transponder processes a Mode 1 challenge, a reply pulse train is transmitted containing two framing pulses 20.3 μsec apart, plus 0 to 5 information pulses (dependent upon the Mode 1 control dial settings). The information pulses are spaced in multiples of 2.9 μsec starting from the initial framing pulse. The position where a sixth pulse (17.4 μsec) would appear is not used. The information pulses are designated by a letter, with a number subscript, in order to identify a specific reply pulse. The subscript numbers are constructed in binary form (1, 2, 4, and so on). In the case of Mode 1, a maximum of three A pulses are possible (A, A_2, and A_4) and a maximum of two B pulses (B_1 and B_2) are available. These reply codes (pulses) are set by the two control dials (M-1) on the control box. The left dial is used for setting the A reply pulses and the right dial is for the B pulses. In figure 3-31, all five of the information pulses are present in the reply train. This corresponds to the maximum dial setting of Mode 1 which is 73. (The left (A) dial has 8 settings 0 through 7, and the right (B) dial has 4 settings 0 through 3, which gives a maximum of 32 possible codes available.) The way to construct a specific reply pulse train is governed by the addition of the particular pulse (such as A) subscript numbers. As an example, if 0 were selected on the left M-1 (A) dial, no A pulses would be present in the reply train. If 1 were selected, only the A_1 pulse would be present in the reply train. If 3 were selected, the A_1 and A_2 (by adding subscript numbers you get 3) would be present, and so on. Keep in mind that any number (0 through 7) selected on the A control dial would read out in binary form in the A pulses subscript numbers. So, for figure 3-31 Mode 1 reply pulse train, with A_1, A_2, and A_4 pulses present, the dial setting is 7 ($1 + 2 + 4 = 7$).

When the transponder processes either Mode 2, 3/A, or test challenges, a reply pulse train is transmitted containing two framing pulses 20.3 μsec apart, plus 0 to 12 information pulses (dependent upon the respective dial settings for each mode). The information pulses are spaced in multiples of 1.45 μsec apart, starting from the initial framing pulse. The position where the seventh pulse (10.15 μsec) would appear is

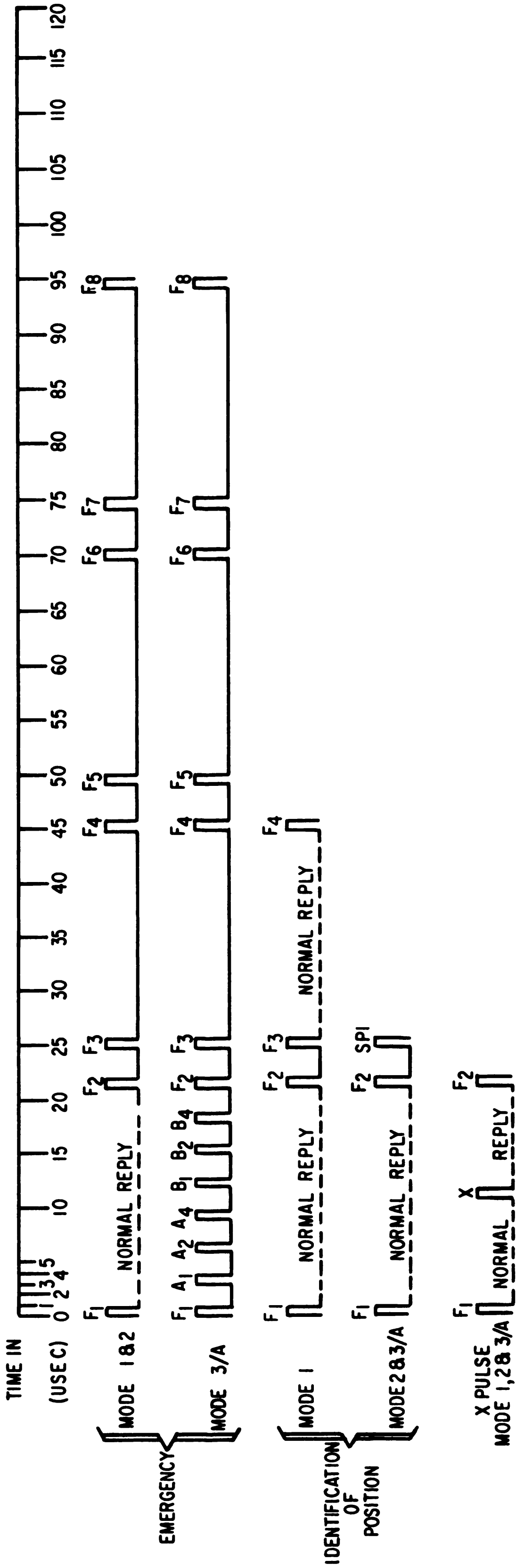

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Figure 3-32.—Special reply pulse characteristics.

normally not used. (This position, called the X-pulse position, will be explained later in this chapter.) As in Mode 1 the 12 information pulses are designated by a letter and subscript numbers. Since Modes 2 and 3/A have four code dials (labeled M-3/on the control box and M-2 on the front of the transponder), there are four possible reply pulses which can be set. They are labeled "A," "B," "C," and "D" and correspond to the four control dials from left to right. The four control dials (for Modes 2 and 3/A) have 8 settings each (0 through 7) for a total of 4096 available codes ($8 \times 8 \times 8 \times 8 = 4096$). As in Mode 1, the various pulse subscript numbers are in binary form of a particular pulse dial setting. In figure 3-31, all twelve information pulses are present in the reply train, signifying a dial setting of 7777. (Add A subscript, B subscript numbers, etc., to obtain the dial reading.) If the dial setting for Mode 3/A were 1, 2, 3, 4, then the pulses present in the reply train would be A_1, B_2, C_1, C_3, and D_4. Remember, the dial setting will read out in binary form in the reply pulse subscript numbers.

The Mode C function of the transponder (altitude reporting) is often referred to as AIMS. When this function was first introduced, it was believed that AIMS was an acronym for Altitude Information Monitoring System. However, this is not true. AIMS is actually an acronym made up of other acronyms.

A.... ATCRBS

I..... IFF

M ... MARK XII identification system

S .... System

When the transponder processes a Mode C challenge, a reply pulse train is transmitted containing two framing pulses 20.3 μsec apart, plus 10 information pulses (as determined by an external pressure altitude digitizer based on the aircraft's pressure altimeter reading). The information pulses are spaced 1.45 μsec apart from the initial framing pulse. The positions where the 7th (10.15 μsec), 9th (13.05 μsec) and 11th (18.85 μsec) pulses would appear are not used. From the 10 information pulses, a total of 1024 codes are available ($8 \times 8 \times 8 \times 2$). Note that (fig. 3-31) in Modes 2, 3/A and C, the pulse positions are not in sequence (A, B, C, etc.) as they are in Mode 1. However, reading the subscript numbers for A pulses will give you the A dial setting, and B the B dial setting, and so on.

As previously stated, Mode 4 reply pulse coding is accomplished by external crypto equipment and is classified information. This information can be found in technical manuals for the KIT-1A/TSEC equipment.

TRANSPONDER SPECIAL REPLY FUNCTIONS.—The special reply pulse characteristics for Modes 1, 2, and 3/A are shown in figure 3-32. Modes C and 4 are not affected by the special reply functions.

Identification of Position (I/P).—The I/P function is controlled by the IDENT/OUT/MIC (fig. 3-30A) switch and affects the operation of Modes 1, 2, and 3/A. In Mode 1, the reply pulse train containing the code in use is transmitted twice, instead of once, for each interrogation pulse received. The second reply pulse train is spaced 24.65 μsec from the leading edge of the first framing pulse in the first train. In Modes 2 and 3/A, the reply pulse train containing the code in use is transmitted once followed by a special position indicator (SPI) pulse for each interrogation pulse received. The SPI pulse is spaced 24.65 μsec from the leading edge of the first framing pulse of the first train. The result of the extra pulse train in Mode 1 and the SPI pulse in Modes 2 and 3 can be seen in figure 3-28. Two rows of dashed lines appear behind the target, instead of just one row as in normal operation. This feature is normally used to distinguish between two aircraft operating in the same mode and SIF code.

Emergency Reply Mode.—The emergency mode of operation of the transponder is controlled by the master switch. Also, most aircraft have emergency IFF override switches on either the crew seats or the canopy. These switches energize when a crewmember or canopy is jettisoned. These switches bypass the master switch and will automatically turn on the IFF and transmit emergency replies when interrogated.

The emergency function affects the operation of Modes 1, 2, and 3/A. In Modes 1 and 2, the reply pulse train containing the code in use is transmitted once for each interrogation pulse received, followed by three sets of framing pulses and no information pulses. The framing pulses will appear at 24.65 μsec, 44.95 μsec, 49.3 μsec, 69.6 μsec, 73.95 μsec, and 94.25 μsec. For each interrogation pulse received in Mode 3/A, one reply pulse train containing the code 7700 (regardless of the Mode 3 control dial settings) is transmitted, followed by three sets of framing pulses and no information pulses. The framing pulses are spaced the same as Modes 1 and 2. The result of these extra pulses can be seen in figure 3-28. Four rows of dashed lines appear behind the target, instead of just one in normal operation.

X-Pulse.—The X-pulse (10.15 μsec) from the initial framing pulse, appears in a normally unused position of Modes 1, 2, and 3/A. It can only be obtained by modifying the control box. When the control box is modified, all replies in Modes 1, 2, and 3/A will include this pulse along with the normally selected information reply pulses, between the two framing pulses. To date, the use of this pulse has been restricted to drones.

As you can see, with the capabilities of the IFF/SIF system to respond with over 8100 reply codes in Modes 1, 2, and 3/A, plus the encrypted Mode 4, and the ability to report altitude information, the system allows for positive identification at long range, and aids greatly in air traffic control.

CHAPTER 4

ELECTRONIC COUNTERMEASURES (ECM)

In today's world of modern electronics technology, any country's military service can, by employing the various communications, navigation, and radar equipment, be a potent fighting force. Without the use of these equipments, the efficiency and effectiveness of the military forces would be greatly reduced. It was recognition of this fact that brought about the development of electronic countermeasures (ECM) equipment. The purpose of ECM equipment is to detect, analyze, locate, and degrade the use of any enemy's electronic warfare equipment. To accomplish this, the Navy employs three basic categories of airborne ECM systems. They are: Passive ECM (PECM), Defensive ECM (DECM), and active ECM (designed to jam or block an electronics system). The objective of this chapter is to acquaint you with the basic concepts of these ECM systems. However, due to the security classification of ECM equipment, no in-depth theory or circuitry can be given in this manual.

SIGNAL CHARACTERISTICS

In order to prepare effective countermeasures against communications and navigation equipments, certain vital information is required; such as, the frequency of transmission/reception, type of modulation used, polarization of the transmitted wave, and the exact location of the system. For countermeasures against radar systems, much more information is required. The principal signal characteristics or "fingerprints" of importance are: the carrier frequency, the pulsewidth of the transmitted signal, the pulse repetition frequency (PRF) of the transmitter, the type of antenna scan used, and the beamwidth and polarization of the antenna. From these characteristics, various aspects of the detected radar, such as type and function of the system, can be determined.

CARRIER FREQUENCY

The first step in preparing for an effective deception or jamming operation is determination of the carrier frequency. The frequency of transmission of a radar system can give a clue to its probable use. For example, since lower frequencies experience less atmospheric attenuation of the signal, long-range early-warning radar sites operate at lower frequencies than short-range fire-control radars. Since the wavelength of a signal is inversely proportional to its frequency ($\lambda = \frac{300}{F_{(MHz)}}$), a clue to the design of the antenna and waveguide can be derived. The lower the frequency of a radar, the larger the antenna and waveguide must be. Consequently, airborne and submarine radars, where space and weight are critical, use higher frequencies. Additionally, the carrier frequency tells us the receiver frequency, and that is what we want to deceive or jam.

PULSE REPETITION FREQUENCY

Another distinguishing characteristic of a radar system is its pulse repetition frequency (PRF). The PRF determines the pulse repetition time (PRT = 1/PRF), which is a major factor in determining the maximum range of a radar. Long-range search radars, for example, must use a lower PRF in order for the receiver to be on for the longer period of time needed for reception of the echo signals from distant targets. Short-range fire-control radars, on the other hand, use a higher PRF.

PULSEWIDTH

It is desirable to know the pulsewidth (PW) of a radar signal, since this value determines the minimum range of the system. The PW signifies the time the transmitter is firing (during which time, the receiver is off). The narrower the PW, the lower (shorter) the minimum range.

The PW also often indicates the probable function (purpose) of a radar system. Narrow pulses of 1 μsec or less indicate short-range precision radars with excellent target resolution, such as navigation and fire-control radars. Wide PW normally indicates long-range early warning radars. Many radars, such as airborne radars, can select two or more pulsewidths and PRF depending on their use. Such radars use a medium PW (2-3 μsec) for search operations and a narrow (.5-1.5 μsec) PW for short-range tracking or the attack mode.

TYPE AND RATE OF ANTENNA SCAN

The type of antenna scan (method by which the radar beam searches the target area) is a good indication of the purpose and mode of operation of a radar. Types of scans include 360°, sector, lobe-switching, conical, and spiral. Long-range search radars, for example, use either 360° or sector scans. Height-finding radars use sector or conical types of scan, and fire-control radars use lobe switching.

The rate of scan, or number of scanning sweeps made per minute, is normally related to the probable maximum range of the radar. Slow scanning rates are characteristic of long-range search systems, while short-range tracking and fire-control radars use much higher scan rates.

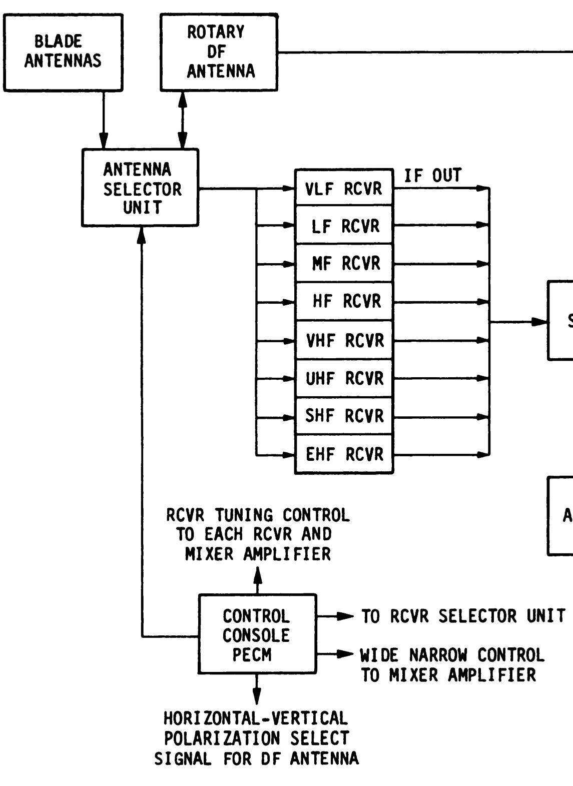

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Figure 4-1.—Typical PECM system utilizing rotary type DF antenna.

BEAMWIDTH AND SIGNAL POLARIZATION

The beamwidth of the transmitted radar signal is normally indicative of the radar system's azimuth accuracy. The width of the beam is normally expressed by the number of degrees between the half-power points of the transmitted RF energy. The narrower the beamwidth, the more accurate the azimuth indication of the radar.

The polarization of the transmitted signal will indicate the polarization of the antenna-horn radiator. This information is necessary in planning effective methods of jamming.

PASSIVE ECM (PECM)

Passive ECM operations are those which cannot be directly detected by the enemy, because no transmissions are made. The purpose or function of PECM equipment is to detect (receive), plot (locate), and analyze the signal characteristics of an enemy's, or suspected enemy's, communications, navigation, and radar equipments. To accomplish this task, a PECM system must have receivers which cover the entire frequency spectrum, a direction-finder (DF) type of antenna system, and indicators with circuitry to analyze and display the various required signal characteristics. This system (PECM) is also referred to as Electronic Support Measures (ESM). The terms PECM and ESM are synonymous.

There are two basic airborne PECM system configurations presently being used by the Navy. The major differences between the two configurations stem from the type of antenna system used and the availability of an onboard computer system. Figures 4-1 and 4-2 are simplified block

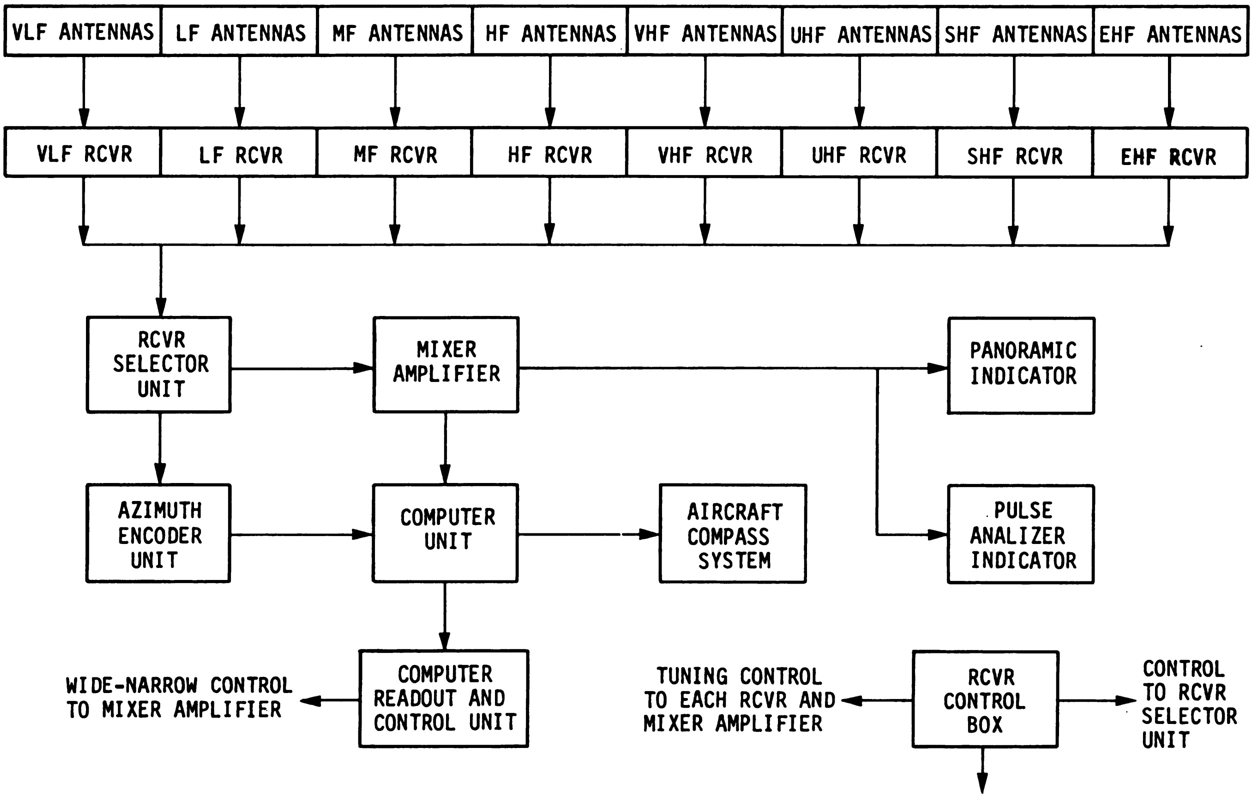

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Figure 4-2.—Typical PECM system utilizing multistationary antennas.

diagrams of the two typical system configurations. Specific systems will vary slightly, but the overall basic concepts of operation are similar. Refer to these diagrams as we discuss each section (unit) of the system.

PECM ANTENNA SYSTEMS

There are two basic configurations of PECM antenna systems. One (fig. 4-1) uses blade antennas and a rotating direction-finder (DF) antenna, and the other (fig. 4-2) uses stationary antennas and computer circuits to determine azimuth information.

The system in figure 4-1 consists of four or five broadband blade antennas, which are used to receive the signals to be processed by the various PECM receiver units. These antennas (figure 4-3) are omnidirectional and nonpolarized. They are basically shorted-stub antennas cut to receive a given wide band of frequencies.

Working in conjunction with these blade antennas is a motor-driven rotating DF antenna. A typical rotating DF antenna is illustrated in figure 4-4. It consists of three separate

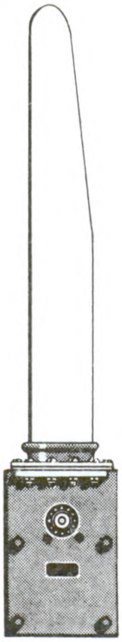
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Figure 4-3.—Typical PECM blade antenna.

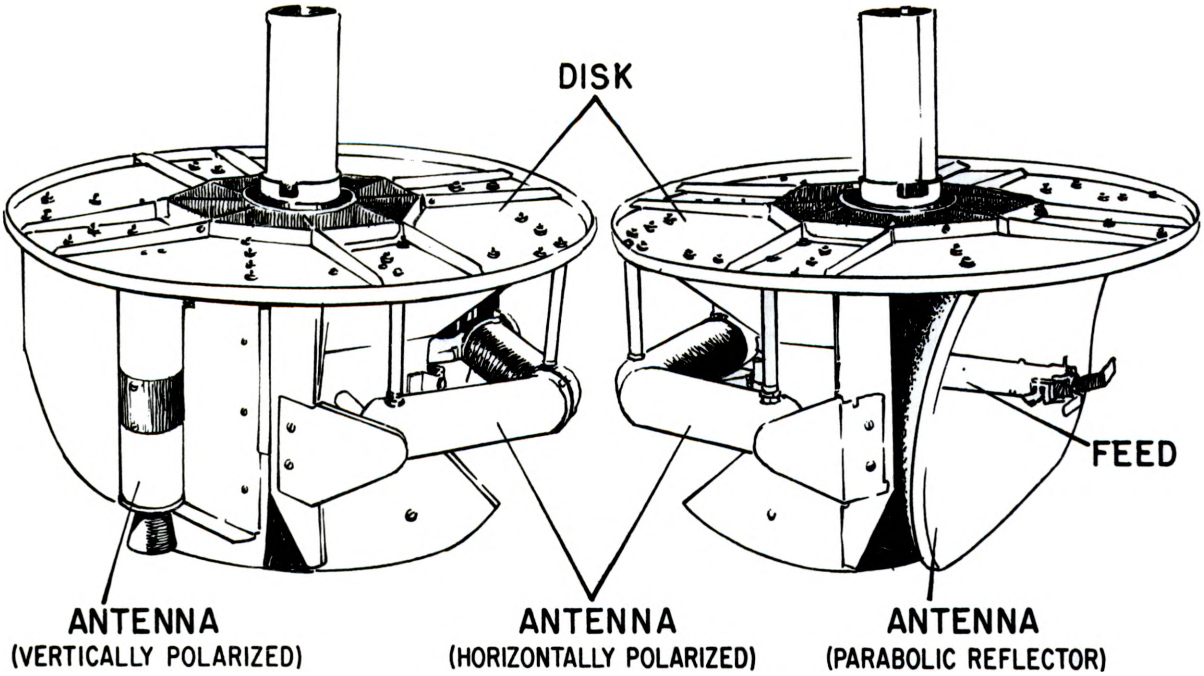

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Figure 4-4.—Typical rotating DF antenna.

sections: a narrow-beam antenna and reflector, a horizontally polarized broadband antenna, and a vertically polarized broadband antenna. The narrow-beam antenna section only receives a signal as it passes through the electromagnetic field of the radiated signal, acting much the same as a radar antenna. The horizontally and vertically polarized antenna sections are broadband, wide-beam antennas, which are used strictly to determine the polarization of the received signal. A switch on the operator's control panel allows the operator to select either the horizontally or vertically polarized antenna, and by determining which antenna yields the strongest signal to the receiver, the operator can establish the signal's polarity. Both the blade and DF antennas feed the received signal to the various receivers for processing. In addition, the DF antenna feeds the received signal to a panoramic indicator via an azimuth synchro resolver unit to display DF patterns. (These DF patterns will be explained later in this chapter.)

The antenna system in figure 4-2, which is the one most widely used, consists of stationary helix, rhombic type, metallic strip antennas, or horn type antennas, depending on the frequency coverage. Each PECM receiver has its own set (normally six) of antennas. These antennas are basically nondirectional, but are mounted on the aircraft (in wing tips, tail sections, fuselage and pods, and so forth) in such a manner that each individual antenna of the set receives maximum signal strength from only a predesigned area (normally 60°) about the aircraft. The complete set of antennas for any one PECM receiver covers a 360° area around the aircraft. Figure 4-5 illustrates the placement of one set of antennas and the area of maximum coverage. These antennas are normally contained in sealed housings. The received signal from each antenna of the set goes to its particular PECM receiver. How DF information is obtained from these antennas will be explained later in this chapter.

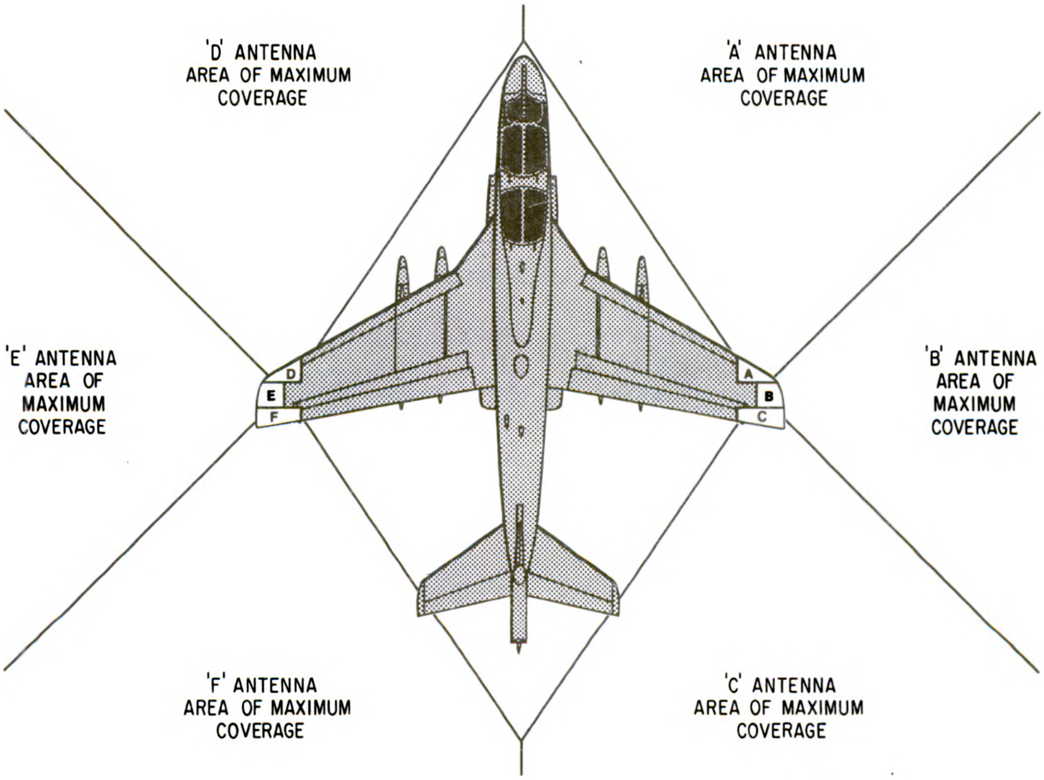

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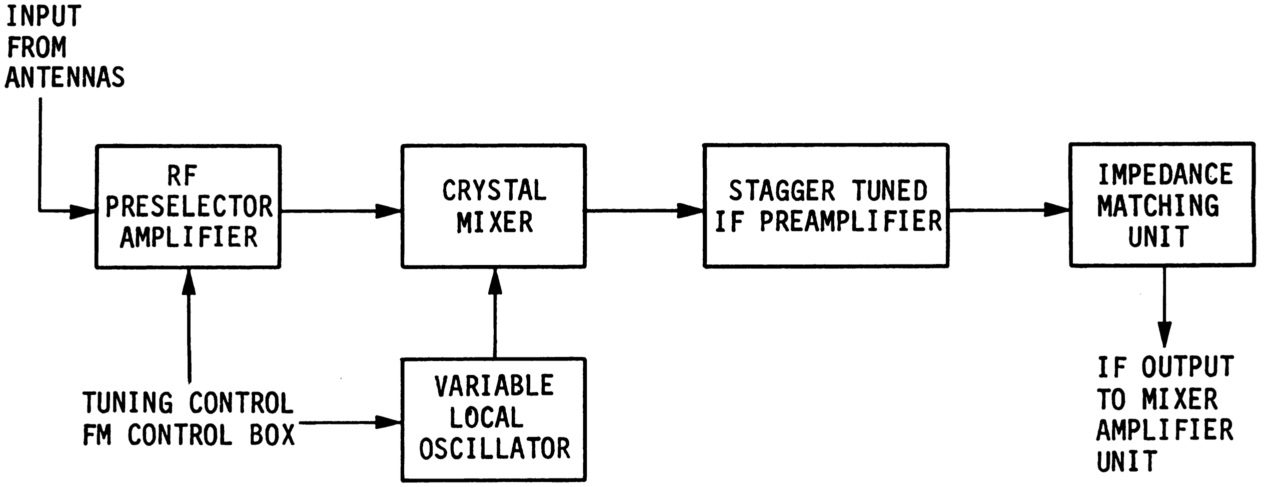
Figure 4-5.—Typical PECM stationary antennas location and area of coverage.


INPUT FROM ANTENNAS
RF PRESELECTOR AMPLIFIER
CRYSTAL MIXER
STAGGER TUNED IF PREAMPLIFIER
IMPEDANCE MATCHING UNIT
IF OUTPUT TO MIXER AMPLIFIER UNIT
TUNING CONTROL FM CONTROL BOX
VARIABLE LOCAL OSCILLATOR

228.187

Figure 4-6.—Typical single channel PECM receiver simplified block diagram.

PECM RECEIVERS

PECM receivers employ typical superheterodyne receiver circuits which are designed to cover a particular band of frequencies. The receivers which are used with the system in figure 4-1 are single-channel receivers, which process the received signal into an IF frequency signal. The output of the receiver is fed to a mixer-amplifier unit for further processing. Figure 4-6 is a simplified block diagram of a typical single-channel PECM receiver.

The input/output circuits of the RF preselector amplifiers and the output of the local oscillator are controlled by either a tuning varactor voltage, or by a tuning dc-operated motor and mechanical linkage, depending on the type of receiver unit. Some receivers use varactor-controlled circuits and some use cavity resonators to control frequency.

In receivers which use cavity resonators to control frequency, the RF preselector and local oscillator are mechanically linked together along with a synchro generator (fig. 4-7), which feeds a frequency signal to the frequency indicator circuit in the indicator.

In receivers which use varactor-tuned circuits, a sample of the control voltage from the control box is fed directly from the control box to the

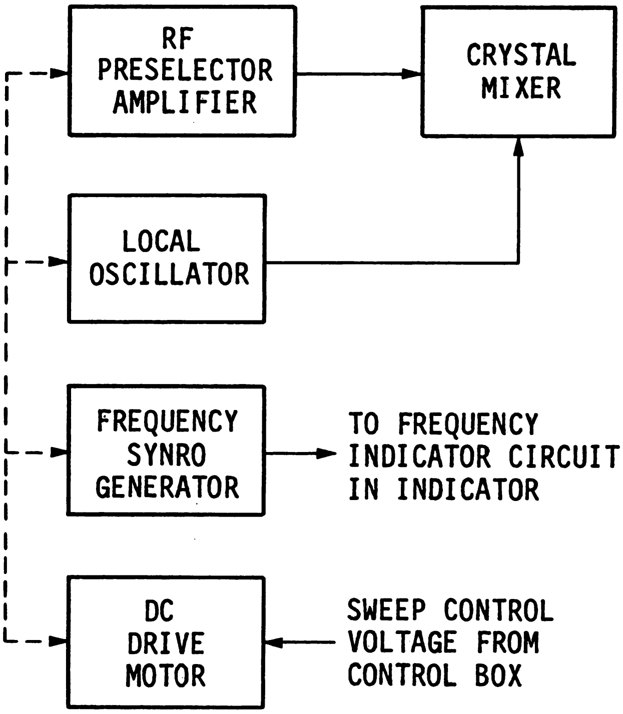

RF PRESELECTOR AMPLIFIER
CRYSTAL MIXER
LOCAL OSCILLATOR
FREQUENCY SYNRO GENERATOR
TO FREQUENCY INDICATOR CIRCUIT IN INDICATOR
DC DRIVE MOTOR
SWEEP CONTROL VOLTAGE FROM CONTROL BOX

Figure 4-7.—Tuning drive for resonant cavity type RF preselector.

frequency-indicating circuits of the indicator. How frequency is displayed will be explained later in this chapter when we discuss the indicators.

The output of the RF preselector amplifiers and the local oscillator are mixed in the crystal mixer, and the IF output is fed to an IF stagger-tuned preamplifier. (In stagger tuning, each stage of preamplification is tuned to a slightly different frequency.) This staggered tuning gives a very broad bandpass which is desirable for video display circuits. The output of the preamplifiers is fed to an impedance-matching network which ensures optimum coupling to the mixer amplifier unit. The sensitivity of the PECM receiver is much greater than that of a conventional communications or radar receiver.

The PECM receivers, which are employed by the system illustrated in figure 4-2, are somewhat more complex. With the use of separate antennas to determine azimuth, the receiver requires a signal-processing channel for each antenna employed. The reason for this will be seen when we discuss the azimuth encoder unit. A simplified block diagram of this type of receiver is illustrated in figure 4-8. The number of channels employed is dependent upon the number of antennas used by the receiver. Since six is most common, we will, for explanation purposes, discuss a six-antenna system throughout this chapter. The number of antennas and receiver channels may vary, but the concept of signal processing is the same.

Each channel of the receiver illustrated contains broadband, constant-gain, RF-amplifier circuits. The outputs of the RF amplifier circuits are fed to the azimuth encoder unit for azimuth processing, as well as to a summing amplifier in the receiver. The single-signal output of the summing amplifier is processed by the rest of the receiver, which is the same as that explained for a single-channel receiver. This IF output is fed to the mixer amplifier unit for further processing.

AZIMUTH ENCODER UNITS

The purpose of azimuth encoder units (fig. 4-2) is to develop a quadrant-locator signal for the computer, convert the received analog signal into a digital signal, and feed the required antenna signals to the computer.

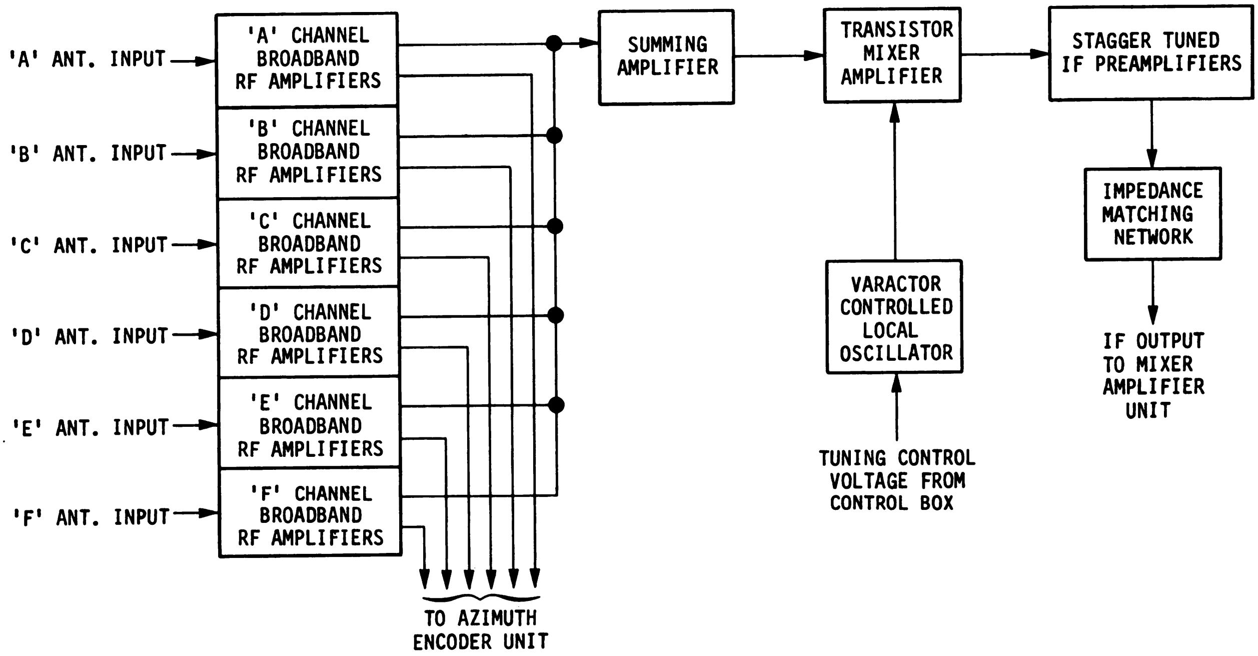

'A' ANT. INPUT
'B' ANT. INPUT
'C' ANT. INPUT
'D' ANT. INPUT
'E' ANT. INPUT
'F' ANT. INPUT
'A' CHANNEL BROADBAND RF AMPLIFIERS
'B' CHANNEL BROADBAND RF AMPLIFIERS
'C' CHANNEL BROADBAND RF AMPLIFIERS
'D' CHANNEL BROADBAND RF AMPLIFIERS
'E' CHANNEL BROADBAND RF AMPLIFIERS
'F' CHANNEL BROADBAND RF AMPLIFIERS
TO AZIMUTH ENCODER UNIT
SUMMING AMPLIFIER
TRANSISTOR MIXER AMPLIFIER
VARACTOR CONTROLLED LOCAL OSCILLATOR
TUNING CONTROL VOLTAGE FROM CONTROL BOX
STAGGER TUNED IF PREAMPLIFIERS
IMPEDANCE MATCHING NETWORK
IF OUTPUT TO MIXER AMPLIFIER UNIT

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Figure 4-8.—Typical multichannel PECM receiver simplified block diagram.

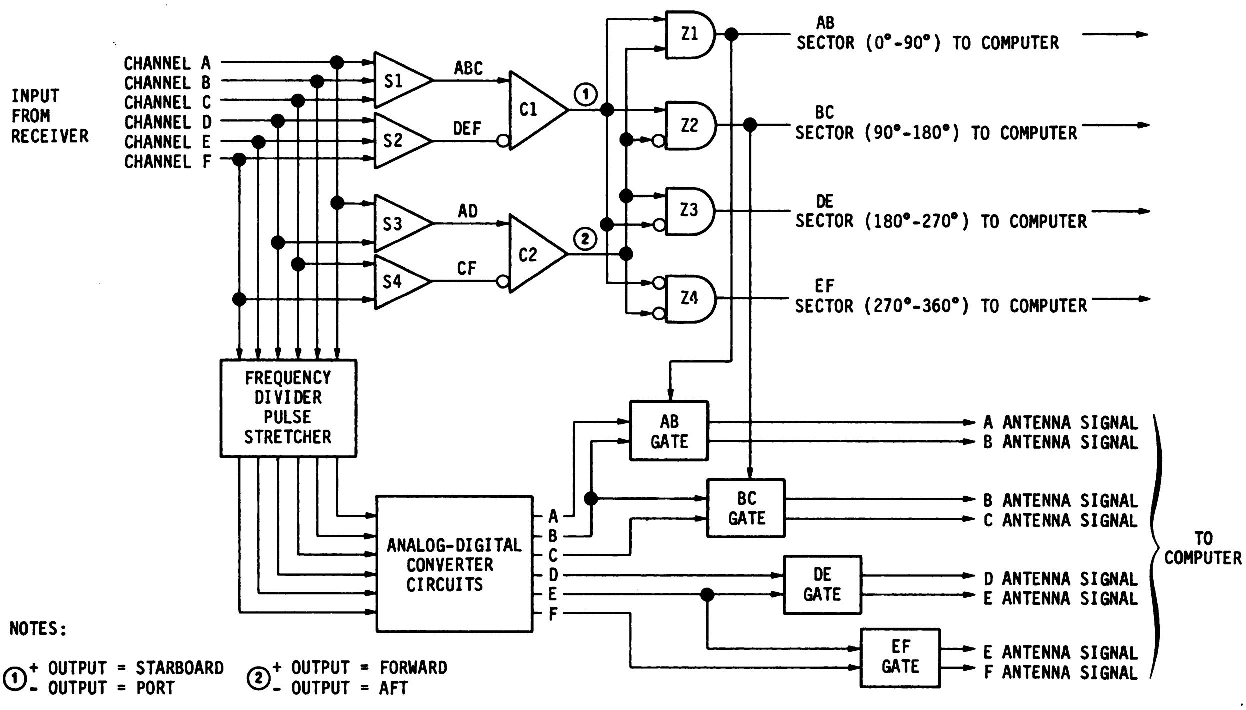

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Figure 4-9.—Typical azimuth encoder simplified block diagram.

Figure 4-9 is a simplified block diagram of a typical azimuth encoder unit. Actual circuits may vary depending upon the desired outputs of a particular system's encoder, but again the basic concepts of the azimuth resolving operation are similar. The six antenna signals from the receiver are fed to various summing amplifiers. Channels A, B, and C are fed to summing amplifier S1. The output of S1 is a composite ABC signal which represents the starboard side (0° – 180°) of the aircraft. (Refer to figure 4-5.) Channels D, E, and F are fed to summing amplifier S2. The output of S2 is a composite DEF signal which represents the port side (180° – 360°) of the aircraft. Also, channels A and D signals are fed to summing amplifier S3. The output of S3 is a composite AD signal which represents the forward sector (270° – 090°) of the aircraft. Channels C and F are also fed to summing amplifier S4. The output of S4 is a composite CF signal, which represents the aft sector 090° – 270°) of the aircraft.

The ABC signal (S1) is fed to the noninverting input of comparator C1 and the DEF (S2) signal is fed to the inverting input of comparator C1. A positive output of C1 would indicate the received signal is coming from an area on the starboard side (antennas A, B, and C have the strongest signals) of the aircraft. A negative output of C1 (antennas DEF have the strongest signals) would indicate the received signal is coming from an area on the port side of the aircraft. The output of C1 is fed to four AND circuits, Z1, Z2, Z3, and Z4.

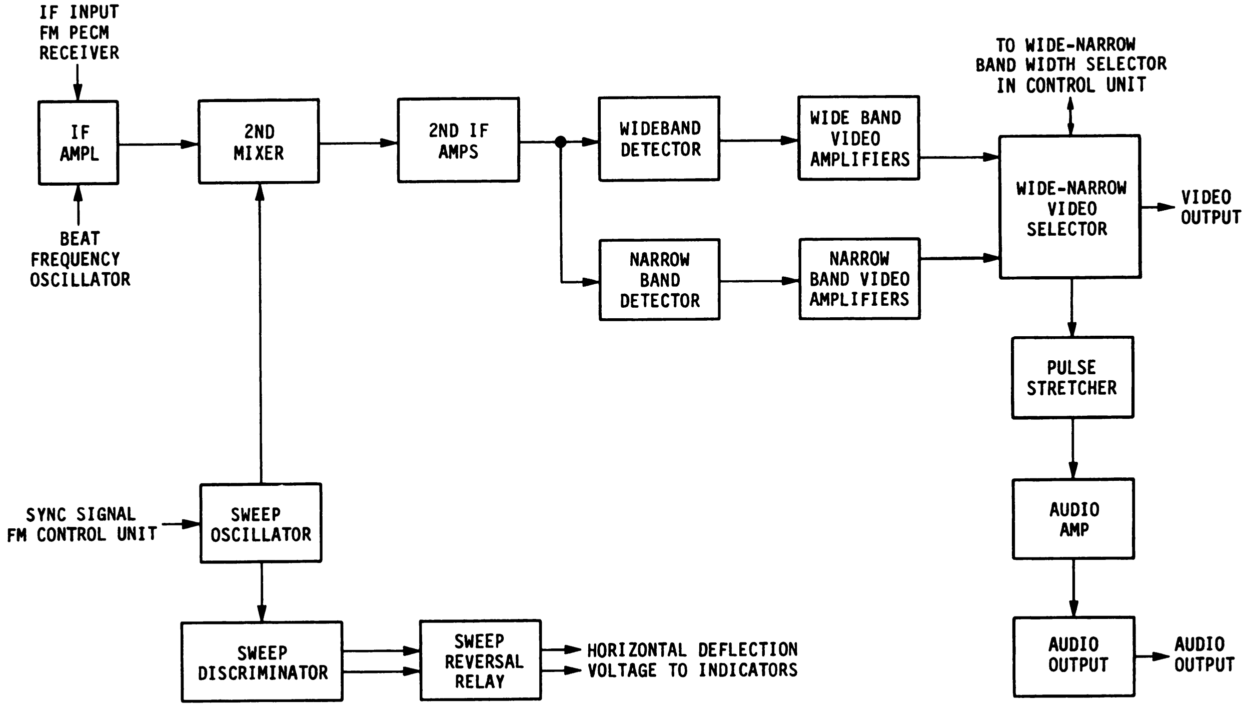
The AD signal (S3) is fed to the noninverting input of comparator C2, and the CF signal (S4) is fed to the inverting input of C2. A positive output of C2 (antennas A and D have the strongest signals) would indicate the received signal is coming from an area forward of the wing beam of the aircraft, and a negative output of C2 (antennas C and F have the strongest signals) would indicate that the received signal is coming from an area aft of the wing beam of the aircraft. The output of C2 is also fed to Z1, Z2, Z3, and Z4. Because the input signals are applied to Z1 through Z4 either directly or through an inverter, each AND circuit represents a 90° quadrant (area) about the aircraft. For example, let us assume the received signal was coming from an 050° relative bearing from the aircraft illustrated in figure 4-5. This would cause antennas A and B to have the strongest signals applied since they are designed to receive maximum energy from that area about the aircraft. The output of comparator, C1, would be positive as the ABC composite signal would be larger than DEF. This positive output would be one enable for Z1 and Z2. Since the output of C1 applied to Z3 and Z4 is inverted in the input, Z3 and Z4 would be disabled and could not give a positive (logic) output. Since the received signal is strongest on antenna A, as compared to C, D, and F, the output of C2 would also be positive (AD signal larger than CF). The output of C2 is applied directly to Z1 and through an inverter to Z2. Two enables (logic 1) inputs for Z1 would give a logic 1 output. Z2 would be disabled. A logic 1 out of Z1 goes to the computer and signifies to the computer that the received signal is located in the 0° to 90° relative quadrant.

The logic 1 output of Z1 is also applied to the AB gate in the encoder. This opens the gate and allows the A and B antenna signals to go to the computer. Gates BC, DE, and EF would be closed as they receive their enables from Z2, Z3, and Z4, which have a logic 0 out at this time.

The A and B signals will be applied to the computer's arithmetic section, along with the 0°—90° quadrant indicator out of Z1. The arithmetic circuits will then calculate the precise relative azimuth of the received signal by algebraically adding the A and B signals and calculating the tangent value. This information will be algebraically added to information fed to the computer by the aircraft compass system. This value will then read out on the computer indicator in the form of magnetic bearing to the station.

MIXER AMPLIFIER UNIT

The mixer amplifier unit (see fig. 4-10, 4-1 and 4-2) processes the IF output of the various PECM receivers, which are selected one at a time or combined in computer systems. They are processed first to a lower more efficient second IF frequency and then to a video signal for


IF INPUT FM PECM RECEIVER
IF AMPL
BEAT FREQUENCY OSCILLATOR
2ND MIXER
2ND IF AMPS
WIDEBAND DETECTOR
NARROW BAND DETECTOR
WIDE BAND VIDEO AMPLIFIERS
NARROW BAND VIDEO AMPLIFIERS
TO WIDE-NARROW BAND WIDTH SELECTOR IN CONTROL UNIT
WIDE-NARROW VIDEO SELECTOR
VIDEO OUTPUT
PULSE STRETCHER
AUDIO AMP
AUDIO OUTPUT
AUDIO OUTPUT
SYNC SIGNAL FM CONTROL UNIT
SWEEP OSCILLATOR
SWEEP DISCRIMINATOR
SWEEP REVERSAL RELAY
HORIZONTAL DEFLECTION VOLTAGE TO INDICATORS

228.190

Figure 4-10.—Typical mixer amplifier simplified block diagram.

display by the indicators. In addition, it develops a synthetic audio signal (representing the received signal) and provides the indicators with horizontal sweep voltages.

The IF signal from the PECM receiver is amplified and applied to a second mixer (the first being in each PECM receiver). The signal is then mixed with the output frequency of a sweep oscillator, which is synchronized with the variable local oscillator of the PECM receiver in use. This results in a lower IF frequency out of the second mixer. This concept of going from one IF to a lower IF is called double conversion, and is done to produce an IF frequency which is easier to amplify and demodulate (detect). The output of the second mixer is applied to IF amplifier stages (tuned to the new lower IF frequency) and then to a narrow-band detector and a wide-band detector. The outputs of both detectors are amplified by video amplifier stages and applied to a wide- narrow-band gating circuit. The gating circuit is controlled by a wide-narrow selector switch on the control unit.

During wide-band (normal mode) operation, the PECM receiver may receive more than one signal around the same frequency due to the broad bandpass of the receiver. To eliminate unwanted signals in order to observe one at a time, the narrow band of operation is selected. Because the bandpass of the narrow band of operation is so small (about 10 kHz), all unwanted signals can be tuned out by the operator to display only one signal at a time on the indicators.

The video output signal is applied to the vertical deflection circuits of the various indicators. Also, in aircraft with computer systems, the video output is applied to the computer for analysis.

The video signal is also applied from the gating circuit to a pulse stretcher, an audio amplifier, and an audio output stage. This audio output goes to the operator's ICS system and is representative of the received signal.

The output of the sweep oscillator is also applied, via a sweep discriminator and a sweep reversal relay, to the horizontal deflection circuits of the system's indicators. In this manner, the received video signal and the indicator's horizontal sweep will be synchronized. This relationship is important, as you'll see when we discuss indicator displays.

PECM INDICATOR UNITS

The purpose of the various PECM indicators is to give the operator a visual picture or digital readout of the received signal, to enable the operator to analyze and determine the required signal characteristics, and to plot the location of the transmitting station. Although various systems use various indicators, there are basically only three types of indicators. They are classified

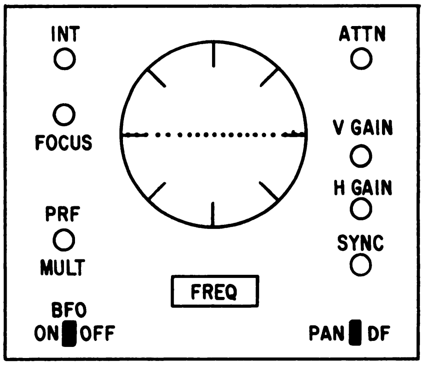
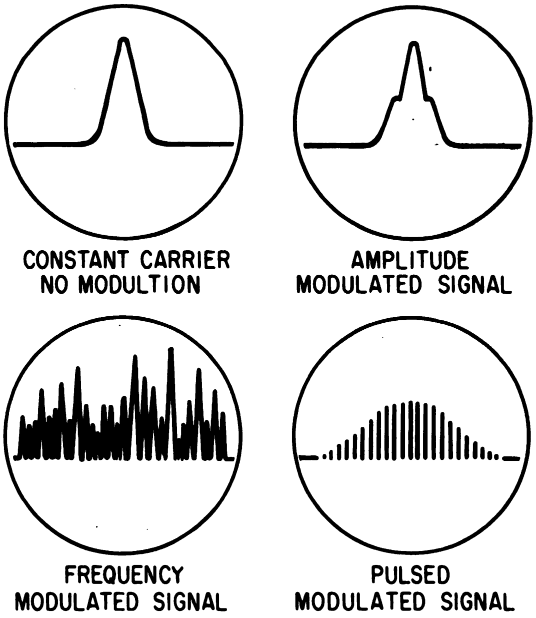


Figure 4-11.—Typical panoramic adapter/DF indicator.


CONSTANT CARRIER NO MODULTION

AMPLITUDE MODULATED SIGNAL

FREQUENCY MODULATED SIGNAL

PULSED MODULATED SIGNAL

Figure 4-12.—Typical panoramic/DF indicator PAN mode patterns.

as panoramic adapters, pulse analyzers, and digital display indicators.

Panoramic Adapter Indicators

Panoramic adapters are specialized indicators used for monitoring a wide range of frequencies. Indicators of this type are used to determine the frequency and bandwidth of the received signals; and, in the case of the system illustrated in figure 4-4 (rotating DF antenna), display DF information.

A typical panoramic/DF indicator is illustrated in figure 4-11. This indicator has two modes of operation, a single horizontal sweep (similar to an oscilloscope), and a rotating PPI type sweep (similar to a radar indicator). In the PAN (horizontal sweep) mode of operation, the scope will display patterns as illustrated in figure 4-12. From the display, the operator can determine the frequency (by reading the frequency indicator which is coupled to the particular receiver in use) and the type of signal being received (CW, MCW, AM, FM, or pulsed).

In the DF mode of operation, the scope will display DF patterns as illustrated in figure 4-13. From this display the operator can determine the bearing to the transmitter by taking the center of the pattern and checking the compass card reading which is on the face of the scope. In addition, the type of signal can be estimated (pulsed, lobe switching, and so forth) from the various shapes of the pattern. The effectiveness of this type of indicator is largely dependent on the expertise of the operator.

Figure 4-14 is an illustration of a typical panoramic indicator used with the type of system (computer) illustrated in figure 4-2. The indicator shown has seven horizontal sweeps. Five of these (labeled 4, 5/6, 7, 8, 9) represent a particular PECM receiver or band of frequencies. Together, the five sweeps represent the entire frequency spectrum covered by the PECM system. All signals received in the entire frequency spectrum will appear as positive spikes on the sweep representing the receiver which detected it. The sweeps on the indicator, the receiver's local oscillators, and the mixer amplifier's local oscillator are synchronized. (The indicator sweeps start at the same time the oscillators are at their lowest frequency and end when they reach their highest frequency.) Thus the positive spike (received video signal) will appear at a point along the sweep which corresponds to the precise frequency. A faceplate (not shown) will enable the operator to read the frequency. By the use of

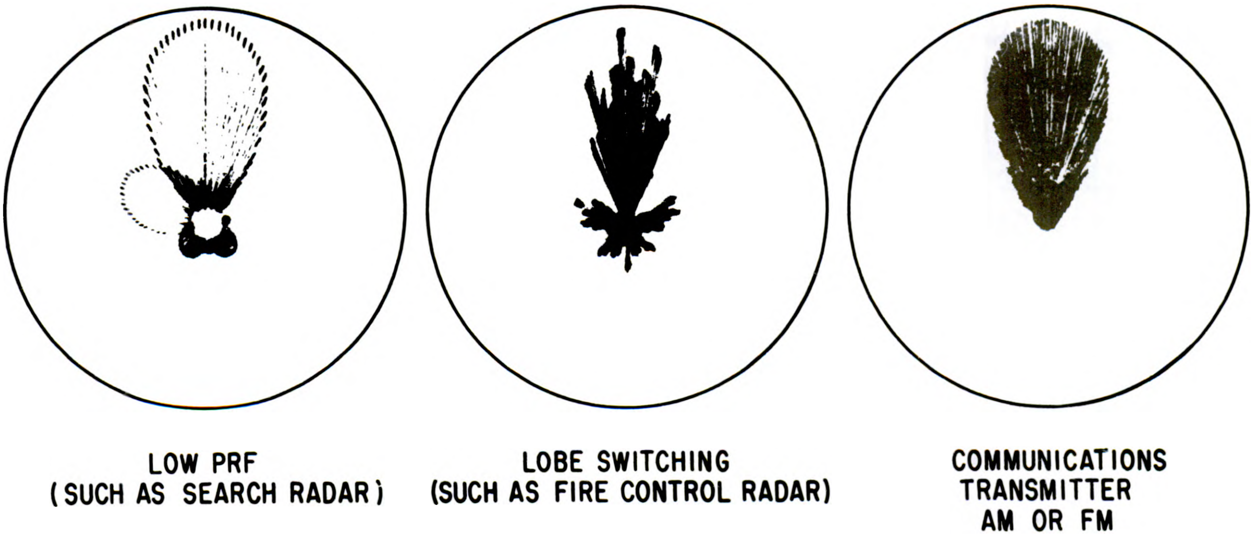
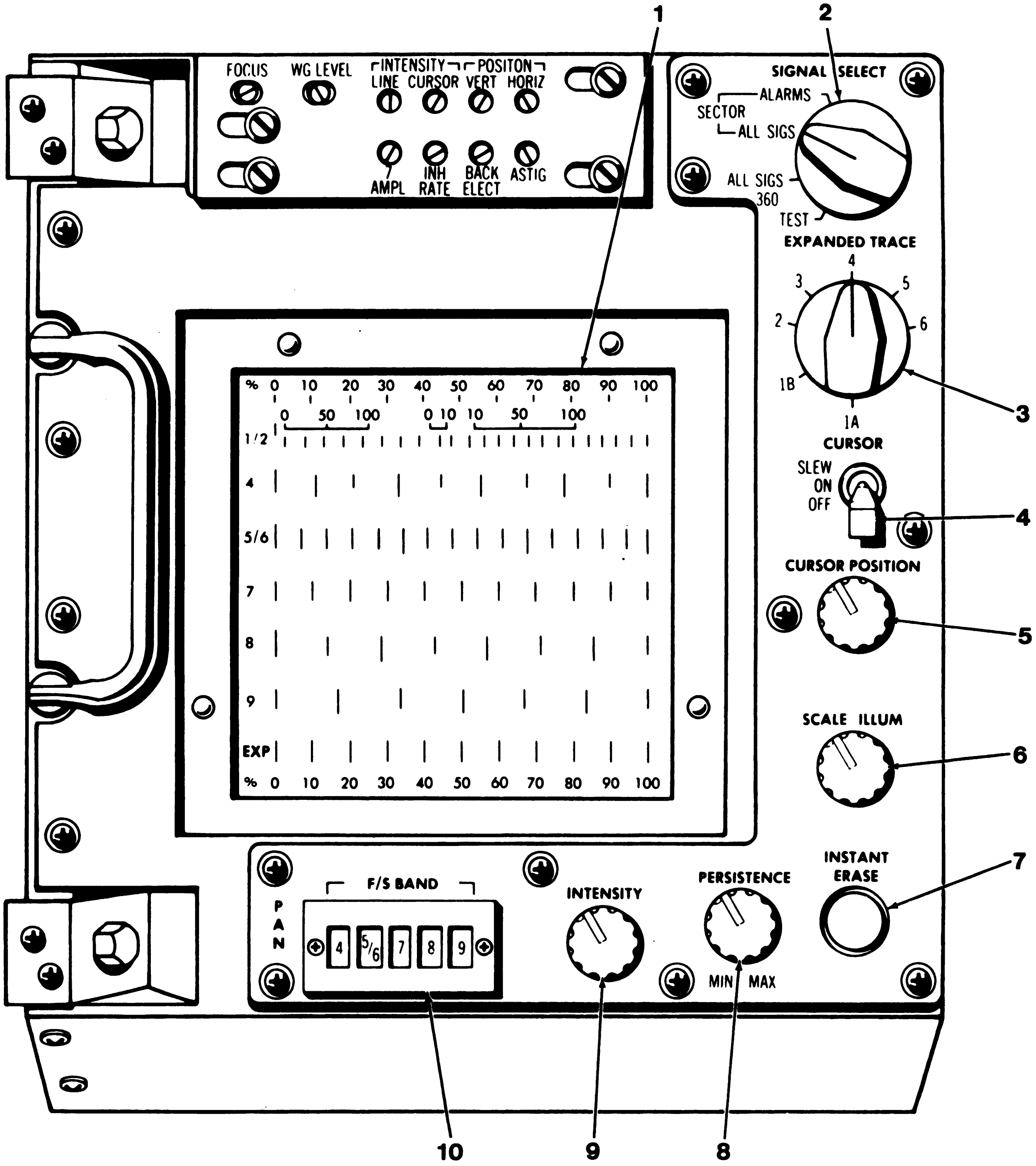


Figure 4-13.—Typical DF patterns.



1. PANORAMIC DISPLAY STORAGE TUBE
2. SIGNAL SELECT SELECTOR SWITCH
3. EXPANDED TRACE SELECTOR SWITCH
4. CURSOR TOGGLE SWITCH
5. CURSOR POSITION CONTROL
6. SCALE ILLUM CONTROL
7. INSTANT ERASE PUSHBUTTON SWITCH
8. PERSISTENCE CONTROL
9. INTENSITY CONTROL
10. F/S BAND INDICATORS

228.191

Figure 4-14.—Typical multisweep panoramic indicator.

a cursor, the operator can select a particular signal for display on the two remaining sweeps of the indicator in order to analyze the bandwidth characteristics. Used in conjunction with this indicator in computerized systems are various digital indicators, which get their information from the computer. Figure 4-15 is an illustration of one of these. Note that the operator has a digital readout of the frequency, PRF, and bearing of the signal selected on the panoramic indicator with the cursor. Also, indicator lights are provided which give the operator various other signal characteristics that are computed. The quantity of characteristics given is dependent upon the complexity of the computer.

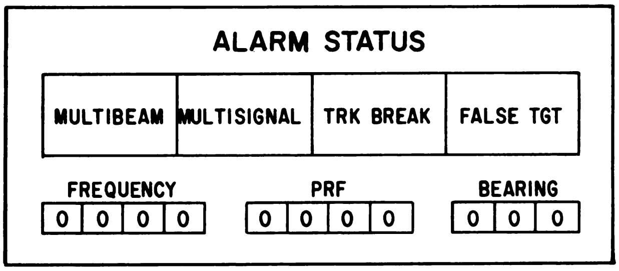
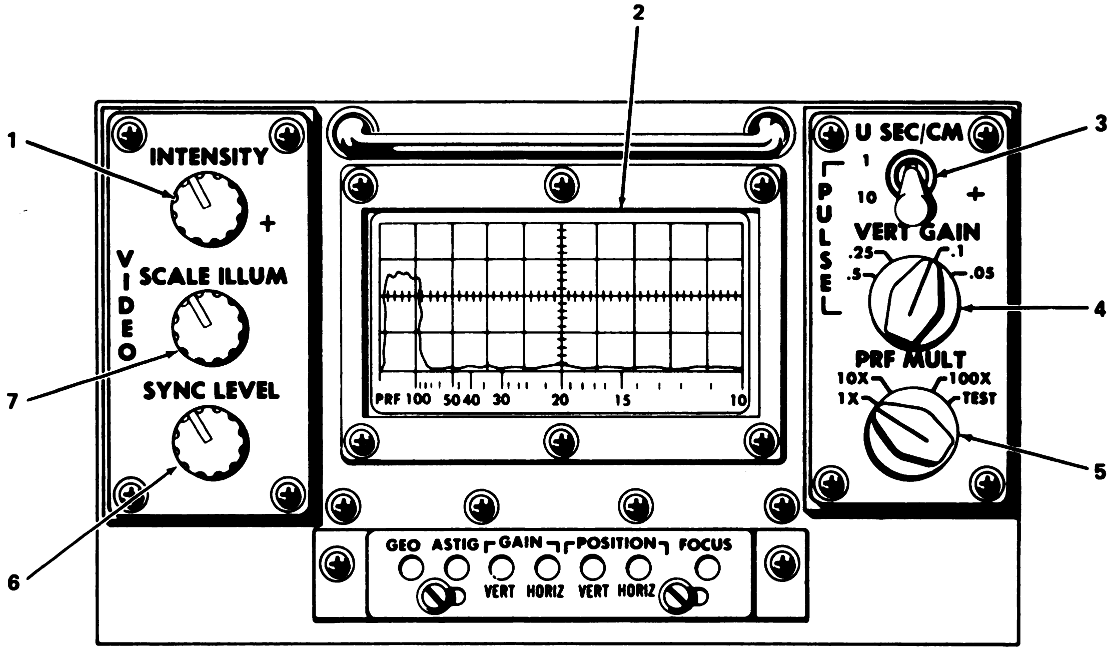


Figure 4-15.—Typical digital display indicator.

PULSE ANALYZER INDICATORS

The purpose of pulse analyzer indicators is to display a particular single received video signal in order to determine the pulse width (PW) and PRF of the signal. Figure 4-16 is an illustration of a typical pulse analyzer indicator. The indicator



1. VIDEO INTENSITY potentiometer
2. Cathode Ray Tube
3. PULSE—USEC/CM toggle switch
4. PULSE—VERT GAIN selector switch
5. PRF MULT selector switch
6. VIDEO—SYNC LEVEL potentiometer
7. VIDEO—SCALE ILLUM potentiometer

228.192

Figure 4-16.—Typical pulse analyzer indicator.

has two horizontal sweeps; one to display a pulse to determine PW; and a second sweep, which displays synthetic blips, to determine the signal's PRF. The operation of this type of indicator is similar to a dual-trace oscilloscope.

DEFENSIVE ECM (DECM)

Defensive ECM (DECM) equipment was designed primarily to protect a single aircraft against an enemy radar. This equipment is also referred to as deceptive ECM systems, because it deceives rather than jams a radar system. There are two basic categories of DECM equipment. They are electronic and nonelectronic DECM.

ELECTRONIC DECM EQUIPMENT

Various types of electronic DECM equipments are designed to deceive various types of radars, such as search, fire-control, and the like. The method of deception (such as time delay for search radar and frequency shifting for fire-control radar) may vary, but the operating concept is the same for all of them; i.e., to receive a threat radar signal, inject false information, and retransmit the signal (with false information) with increased power.

Since most radar receivers contain automatic gain control (AGC) circuits, the DECM signal (which is much stronger than the radar's normal echo return signal) will cause these circuits to induce maximum attenuation (decrease the receiver's sensitivity) thereby hindering the receiver from detecting the normal echo signal (which is weak) and causes the radar to display only the DECM signal on the radar's indicator. Figures 4-17A and 4-17B illustrate the result of DECM deception using the time-delay method. The DECM equipment in this case receives the threat radar signal, amplifies it, detects the pulse, delays the pulse a few μsec and retransmits the pulse (normally using a traveling wave tube (TWT)), with increased power. The result of delaying the received signal deceives the threat radar into believing the aircraft is farther away than it actually is. This is because radar range is based on the time it takes the transmitted pulse to travel to a target and return (Note: 12.36 μsec = 1 range mile). Since the DECM signal overrides the normal echo return signal, the radar receiver processes and displays the DECM signal. The DECM equipment constantly varies the amount of time delay for each received pulse, which causes the aircraft target to jump around erratically on the radar's indicator.

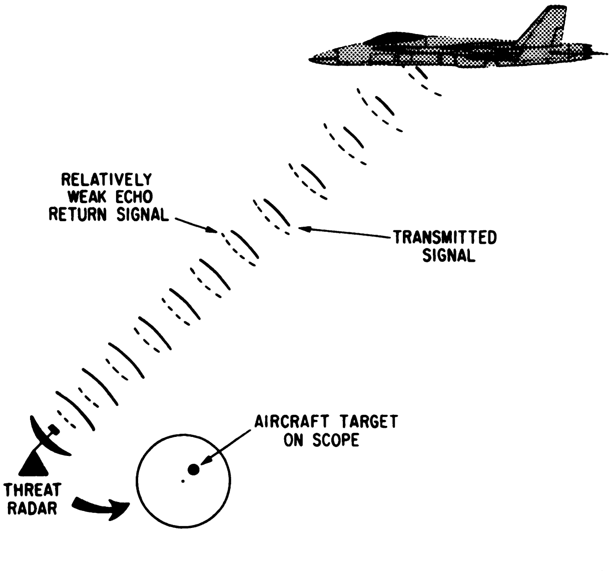


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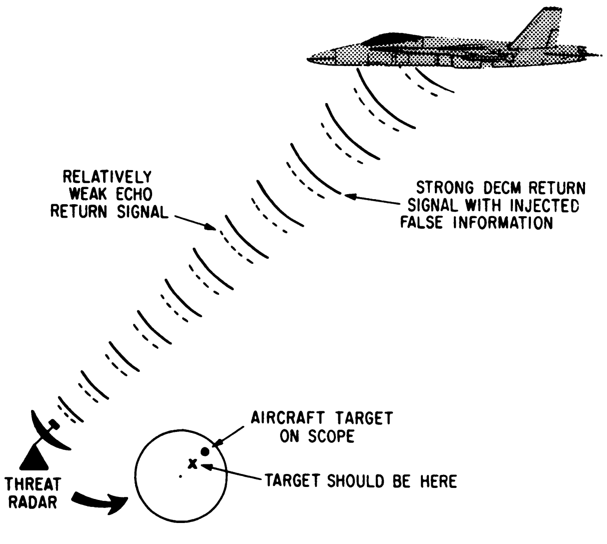
Figure 4-17A.—Normal target reception by a radar.


RELATIVELY WEAK ECHO RETURN SIGNAL
STRONG DECM RETURN SIGNAL WITH INJECTED FALSE INFORMATION
AIRCRAFT TARGET ON SCOPE
TARGET SHOULD BE HERE
THREAT RADAR

228.193.1

Figure 4-17B.—Target reception with DECM deception.

Some DECM equipment will not only inject time delays, but will transmit multiple pulses which show up as multiple targets on a radar's indicator. Regardless of the type of deception used, the threat radar cannot plot the correct location of the aircraft, or in the case of fire-control radar, cannot "lock-on" the aircraft.

Due to the security classification of this equipment, no circuitry can be explained in this manual.

NONELECTRONIC DECM

Another means of deceiving a threat radar is by the use of chaff. Chaff is the general name given to packaged strips of metal foil which, when ejected from an aircraft, disperse into the air and cause multiple echo signals (targets) on the radar's indicator. The metal foil is cut to the correct wavelength of the radar transmitting frequency, so that it will reflect maximum echo signals back to the radar receiver. Figure 4-18 illustrates the effect of chaff on a radar indicator. Each strip of chaff shows up as an individual target on the scope and the operator is unable to tell the chaff target from the aircraft.

"Rope" and "window" are additional names given to chaff. The term "rope" is normally given to longer strips of chaff which are precut to deceive low-frequency long-range radars. The term "window" is given to short strips of chaff which are precut to deceive high-frequency short-range radars.

There are various types of chaff dispensing systems which are designed for use in a particular type of aircraft. These systems can disperse hundreds of pounds of chaff in seconds, or can be programmed to dispense certain quantities of chaff at various time intervals. Due to the security classification of these systems, no illustrations or circuitry can be given in this manual.

ACTIVE ECM

Active ECM is a term given to ECM electronic equipment designed to jam communications, navigation, and radar receivers. These

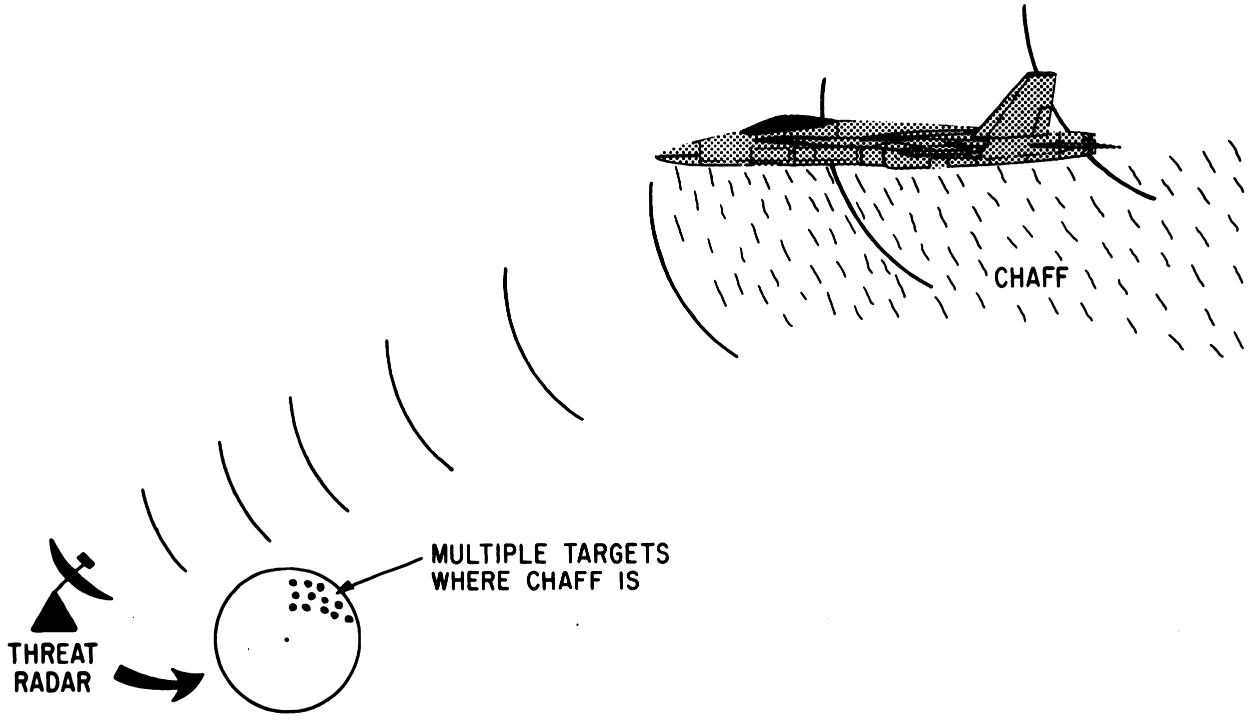


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Figure 4-18.—Target reception with chaff.

"jammers" are high-powered, noise-modulated transmitters, designed to transmit random noise over a given band of frequencies. This high-powered noise will overdrive the receiver of the equipment to be jammed, rendering it useless. In the case of a threat radar, the jammer signal will cause the indicator to "blossom." This is because the jammer's powerful noise signal overdrives the radar receiver's circuits, causing the receiver to put out a constant video signal for an area where the noise signal is stronger than the receiver's maximum sensitivity. In this manner, one ECM jammer can protect (hide) a group of aircraft over a large area. The ECM jammers are usually used in conjunction with PECM systems. The PECM system detects, analyzes, and locates the threat site. Then the jammer transmitter is either automatically or manually tuned to the correct frequency and bandwidth, and so on. The jammers are equipped with rotating-type antennas, which can be aimed at the threat site to concentrate the transmitted energy for maximum effectiveness. Because of the security classification of these jammers, no illustrations or circuitry can be given.

The preceding pages have given you an overview of the concepts, methods, and equipment for electronic countermeasures. You will learn the specifics as you need them on the job.

CHAPTER 5

SUPPORT EQUIPMENT

Support equipment has become as important to the assigned mission of naval aviation activities as the aircraft itself. Many different types of support equipment are required for handling, servicing, loading, testing and maintaining aircraft. Although you as an AT are not responsible for the upkeep and maintenance of support equipment, as a user, you must have a basic knowledge of the equipment's capacity and operation.

MOBILE ELECTRIC POWER PLANTS

The electrical power requirements for starting and servicing modern aircraft are extremely high. Even in aircraft equipped with batteries, and with the batteries fully charged, the capacity is not sufficient to withstand the heavy load of starting an aircraft engine or the power drain of prolonged operational ground checks.

The Navy has expended enormous amounts of time and money in the engineering of power plants which are used for starting aircraft engines and for furnishing power for electrical and electronic circuits when operational ground checks are performed.

NOTE

Batteries are not to be used to start aircraft reciprocating engines except in an extreme emergency. The purpose of an aircraft battery is to operate specific instruments and radios in case of a loss of aircraft generator power.

Increasing numbers of aircraft are being manufactured that have no internal source of electrical power unless the engines are operating. This presents problems in performing maintenance where electrical power is required. Even on aircraft where batteries are installed, use of the battery to perform maintenance is prohibited, so the pilot will have a fully charged battery should it be needed in an emergency. Running the aircraft engines to provide electrical power for maintenance purposes is also poor practice because of the danger of turning propellers, jet intake and exhaust blast, or the expense of operating high powered engines for long periods when only electrical power is required. To facilitate maintenance and to provide instrumentation necessary to monitor engine performance during starts, an external source of electrical power is necessary.

Although ATs are not responsible for the upkeep and maintenance of Mobile Electric Power Plants (MEPPs), you must have a basic knowledge of their capacity and operation. On all of the mobile electric power plants described in this chapter, the ac frequency is automatically controlled by a governor that controls the speed of the power plant. The voltage is controlled by a voltage regulator. If the power plant does not regulate to the proper speed (frequency), it must be serviced by the Support Equipment work center.

There are many and varied types of electric power plants available; some are designed for universal use, while others can be used only on specific aircraft. Therefore, you should consult the Maintenance Instruction Manual for the recommended power plant for the type aircraft being worked on. In the following discussions, no attempt is made to cover all MEPPs that you may encounter.

OPNAV 4790.2 (Series) has established the Support Equipment Operator/Organizational Maintenance Program. This program emphasizes and formalizes the responsibilities and procedures required in connection with the operation of support equipment (SE). (Support equipment is also referred to as GSE (ground support equipment), and you may see this abbreviation used in many publications.)

During recent years, the improper use of SE has resulted in far too many ground handling accidents, excessive repair and replacement costs amounting to millions of dollars annually, and reduced operational readiness. Investigation has shown the major reasons for improper use of this equipment to be lack of effective training for the individuals who operate and maintain the equipment and the lack of effective supervision and leadership by the officers, petty officers/noncommissioned officers directly responsible for such operation and maintenance at the various activities.

NOTE

> A SE operator's license OPNAV Form 4790/102 is required of all personnel who operate SE regardless of rate or rating.

It is emphasized that the SE Training Program is intended to teach ground support equipment operation and organizational level maintenance only. This training does not qualify the individual to operate equipment on the aircraft.

IDENTIFICATION OF MEPPS

There are four categories by which the MEPPs are readily identified: (1) vehicular, self-propelled; (2) trailer-mounted, gasoline or diesel engine driven; (3) trailer-mounted, electrically driven; (4) dolly/skid-mounted, gasoline/diesel engine driven or electrically driven. The various categories of power plants may be further identified by prefix letters NA, NB and NC. These letters indicate the type of power available from the unit as follows:

NA—dc output power only
NB—ac output power only
NC—ac/dc output power

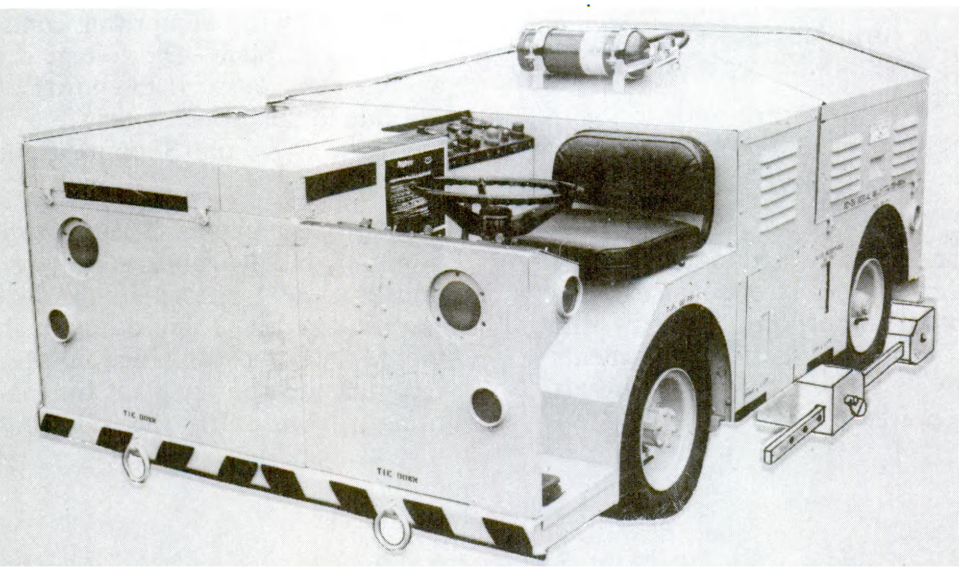

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Figure 5-1.—MEPP NC-2A.

NC-2A

The NC-2A (fig. 5-1) is a self-propelled diesel-engine-powered unit. It is front-axle driven, steered by the two rear wheels, and easily maneuverable in congested areas. The front axle is driven by a 28-volt dc, reversible, variable-speed motor, capable of propelling the unit up to 14 mph on level terrain, and has a turning radius of approximately 11 feet.

The primary source of power is a 3-cylinder, water-cooled diesel engine which drives the ac and dc generators through a speed increasing transmission. All controls, both propulsion and electrical power, are available to the operator on three panels located in the front and to the right of the operator's seat.

The power plant is designed for air transport and is provided with two tiedown rings each on the front and the rear bumpers. Forklift channels are located between the front and rear axles, providing safe lifting points for the unit.

NC-7C

The NC-7C (fig. 5-2) is powered by a V-8 gasoline engine, contains two dc generators, an ac generator, a control console for control of the engine and both electrical power systems, and a propulsion system for moving the power plant under its own power. Access doors are provided for the control console, engine compartment, battery compartment, cable stowage compartment, and tool compartment. A hand-operated control unit is provided on the tow bar for controlling the unit during self-propelling operations. A fire extinguisher readily accessible for emergency use is mounted near the tow bar.

CAUTION

> Do not move the power plant by means of the self-contained propulsion mechanism while supplying power to an aircraft. Under no condition is the power plant to be used for towing other equipment.

The self-propelling feature should be used only when moving from one aircraft to another, or from the line to the hangar if the distance is not too great. For greater distances, the unit must be towed. (Maximum towing speed is 20 mph.)

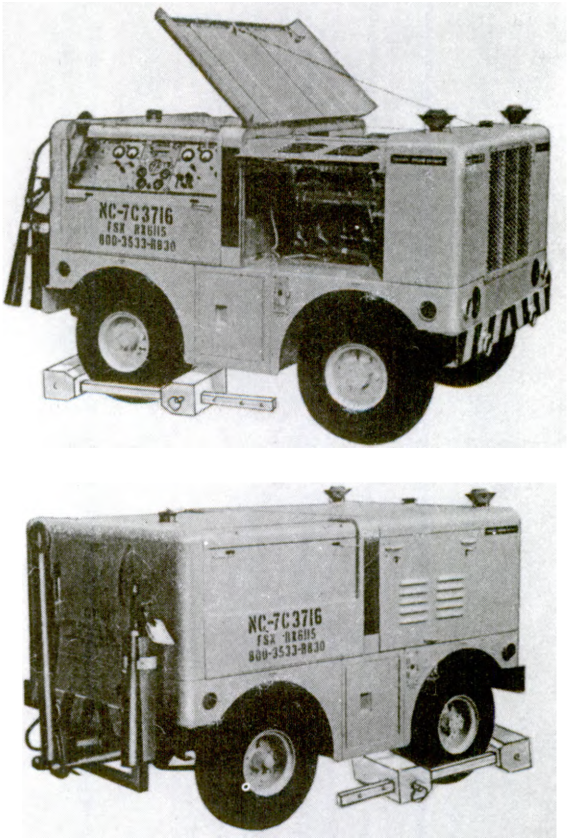

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Figure 5-2.—MEPP NC-7C.

NC-8A

The NC-8A (fig. 5-3) is a mobile, self-propelled unit used for servicing and starting rotary and fixed wing aircraft. It is powered by a 4-cylinder, two-stroke-cycle, diesel engine controlled by an electrohydraulic governor.

This unit has one dual-purpose generator, capable of supplying both ac and dc power simultaneously. It consists of a dc generator and a synchronous alternator enclosed in one housing. The main shaft is connected to the

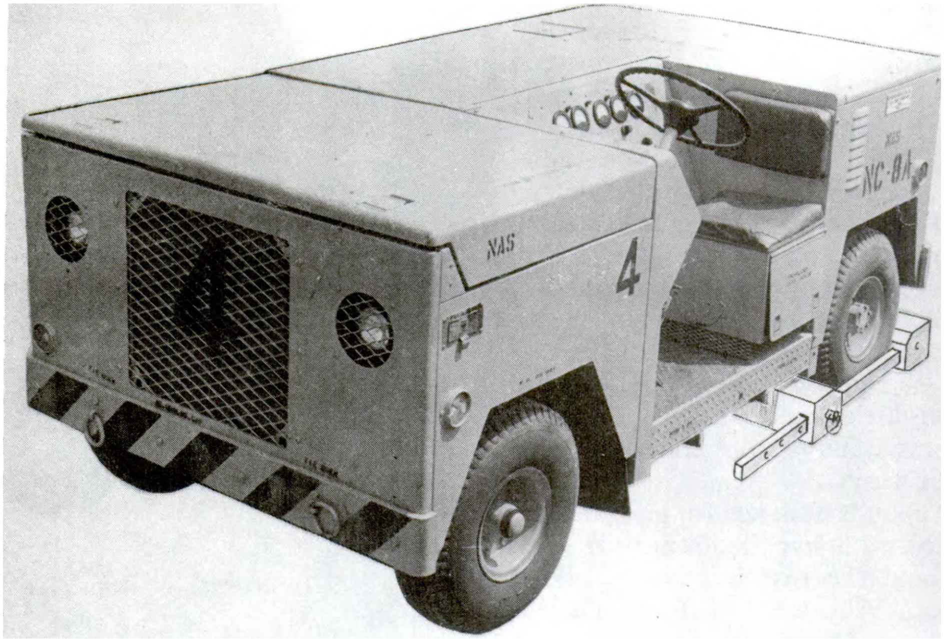

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Figure 5-3.—MEPP NC-8A.

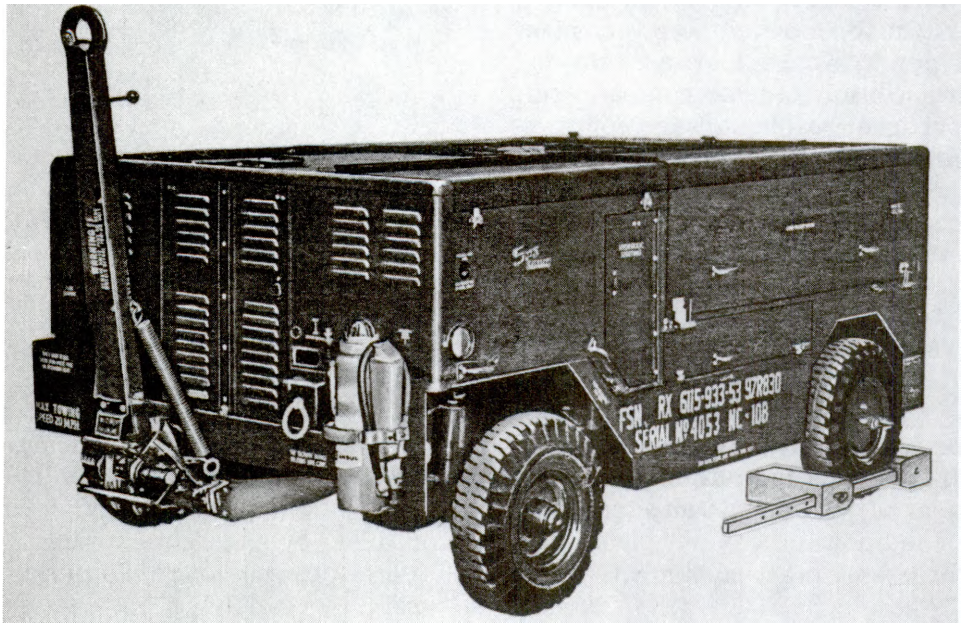

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Figure 5-4.—MEPP NC-10B.

engine by a driving disk which drives the ac generator rotating field and the dc generator rotating armature. Field excitation for the generator is supplied by the vehicle battery. The generator is cooled by two internal fans mounted on the main shaft.

All engine controls and instruments are located directly in front of the operator; controls and instruments for the generator are located to the operator's right.

Vehicle propulsion power is provided by a 28-volt, direct-current, reversible, variable-speed motor. The motor is connected to the rear wheels via an automotive type differential, and speed is controlled by a conventional foot-operated accelerator pedal. The direction of travel is controlled by a switch mounted on the instrument/control panel.

> NOTE: A special feature of the NC-8A serves as a reminder of the necessity for continual alertness in monitoring the actions of inexperienced personnel. This feature is labeled NC-8A Support Equipment Change No. 2436, and is designed to prevent the NC-8A from being driven unless the power cables are properly stowed on the cable reels and the cable heads are plugged into dummy receptacles. The change was issued in response to numerous incidents in which maintenance or line crew personnel tried to tow an aircraft using the mobile electric power plant with the power cables acting as the tow bar.

NC-10B

The NC-10B (fig. 5-4) is a diesel-engine-driven unit designed for shipboard or shore station use. This unit supplies 90-kva, 120/208-volt, 3-phase, 400-Hz power for servicing, starting, and maintaining helicopters and jet aircraft. A portion of the electrical power generated is rectified to supply 28 volts dc at 750 amperes (1,000 amperes intermittent) for aircraft starting.

The power plant is enclosed in a steel housing, fabricated in two sections which are easily removed for servicing the unit. Operating components are mounted on a 4-wheel trailer which is equipped with mechanical-type internal expanding wheel brakes. The brakes may be set by hand lever, and are set automatically when the tow bar is in the vertical position.

Double hinged doors provide access to the control panel, starting components, and three output power cables.

The plant's electrical system is protected from overload by output circuit contactors, circuit breakers, overvoltage and undervoltage relays, overfrequency and underfrequency relays, thermal overload relays, and fuses.

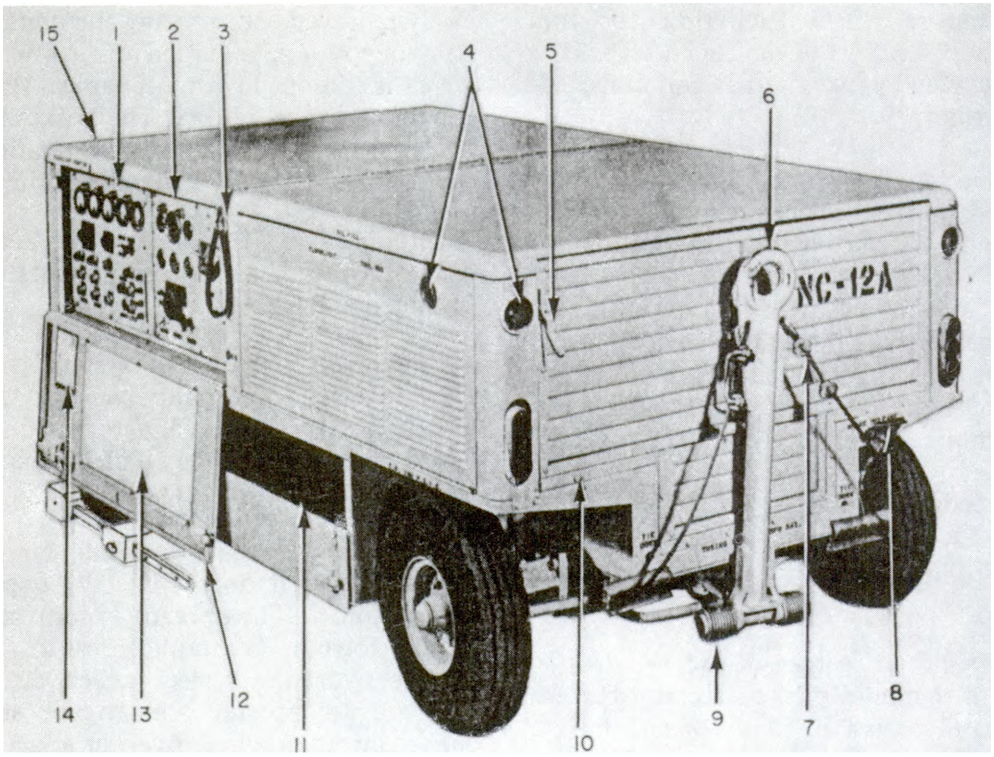
This unit is self-propelled, for movement between aircraft on the line, by two hydraulic wheel motors. The operator's control is located on the towbar. Hydraulic pressure is supplied by the hydraulic system which also provides pressure to operate the engine starter and the electrohydraulic governor's actuator system.

Power generation, both dc and ac is controlled by the operator from the control panel located at the right front of the unit. The control panel contains three functional groups of instruments—the ac controls, the dc controls, and the engine controls.

NC-12A

The NC-12A (fig. 5-5) is a fully enclosed, diesel-engine-driven, dual output power plant. It provides a 120/208-volt, 3-phase, 400-Hz, 125-kva output, or 87.5-kva ac power simultaneously with a 750-ampere, 28-volt dc output. A dc output of 950 amperes can be obtained intermittently when only the dc power is being used.

The generator assembly consists of two brushless ac generators and two brushless exciters, mounted on a common shaft and directly coupled to the engine. The NC-12A provides a dc output by rectifying the output of one of the generators. The generator outputs are



1. **Electrical control panel.**
2. **Engine control panel.**
3. **Chain strap.**
4. **Safety reflectors.**
5. **Manual shutter control lever.**
6. **Tow bar.**
7. **Safety cable.**
8. **Parking brake lever.**
9. **Tow bar return springs.**
10. **Automatic shutters.**
11. **Output cable storage.**
12. **Control panels access door.**
13. **Schematic diagram encapsulation.**
14. **Lubrication diagram encapsulation.**
15. **Floodlight mounting location.**

225.139

Figure 5-5.—MEPP NC-12A.

separately controlled (one by the ac regulator, and the other by the dc regulator.)

The power plant and its components are mounted on a 4-wheel trailer equipped with mechanical rear wheel brakes which are actuated by a hand lever, or by the spring-loaded tow bar. These units are not equipped with self-propelling features, and must be towed.

RCPT-105

The RCPT-105 (fig. 5-6) is a gas-turbine-driven aircraft ground service unit, mounted in a low-silhouette, self-propelled trailer. The low silhouette design and the self-propulsion system enable the unit to be maneuvered in congested aircraft parking areas. It is completely self-contained, and provides compressed air for starting the main engine, ac and dc electrical power for operation of aircraft components, and conditioned air for aircraft compartment cooling and pressure suit ventilation. All controls and instruments for the unit are grouped, by system, on one panel located at the right rear of the unit.

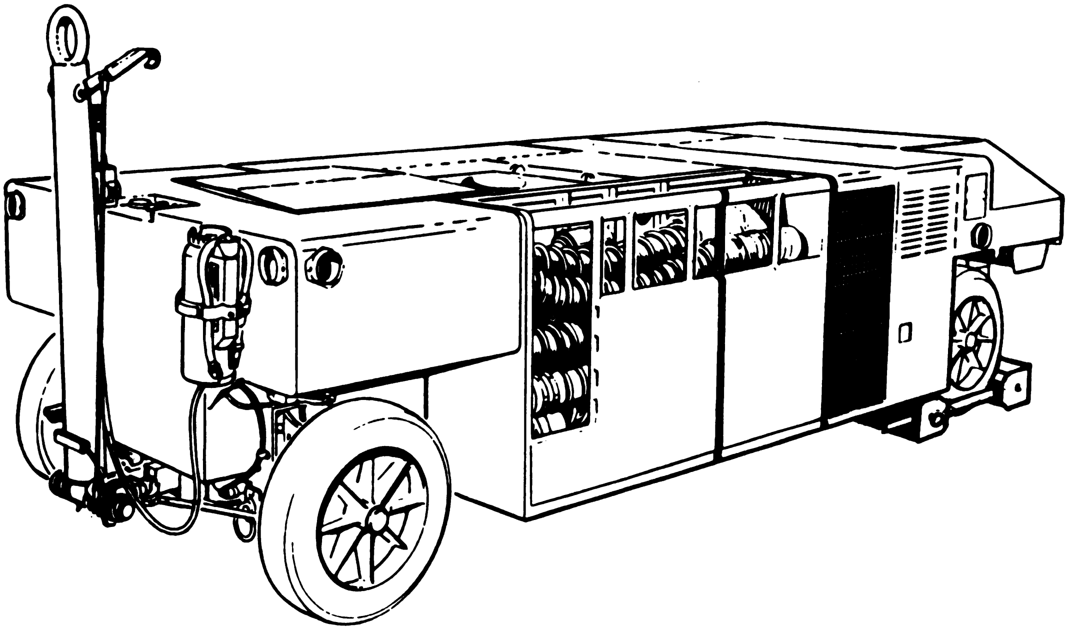


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Figure 5-6.—RCPT-105.

Propulsion System

The RCPT-105 is provided with a self-propulsion mechanism for use in moving the unit over distances not to exceed 2,000 feet on a smooth, level surface. For greater distances, the unit must be towed. Power to operate the 28-volt dc reversible drive motor, located on the rear axle, is provided by the unit's batteries. The operator controls are located on the tow bar, and a time delay relay is used to keep the brakes applied for 4 seconds after the unit is stopped. This delay ensures that the unit is completely stopped before changing direction of travel.

MOBILE MOTOR-GENERATOR SETS

Mobile motor-generator sets (MMGs) perform the same function as the mobile electric power plants, but they are not self-contained and require an external source of electrical power for operation. The MMGs are primarily used in hangars on shore stations, or on the hangar decks of aircraft carriers where the running of an internal combustion engine would be objectionable, and where external power is readily available.

MMG-2

The MMG-2 (fig. 5-7) is physically quite small and very compact. It is a trailer-mounted electric-motor-driven generator set used to provide 120/208-volt, 400-Hz, ac power, and 28-volt dc power for use in ground maintenance, calibration, and support for all fighter/interceptor type aircraft equipment.

MMG RX-400

The RX-400 (fig. 5-8) provides 120/208-volt, 3-phase, 400-Hz ac power, and 28-volt dc power for use in ground maintenance, calibration, and support of aircraft equipment. The motor generator power supply contains two output channels. Channel 1 provides 60-kva, 120-volt ac line-to-neutral, 208-volt ac line-to-line. Channel 2 provides 60-kva, 120-volt ac line-to-neutral,

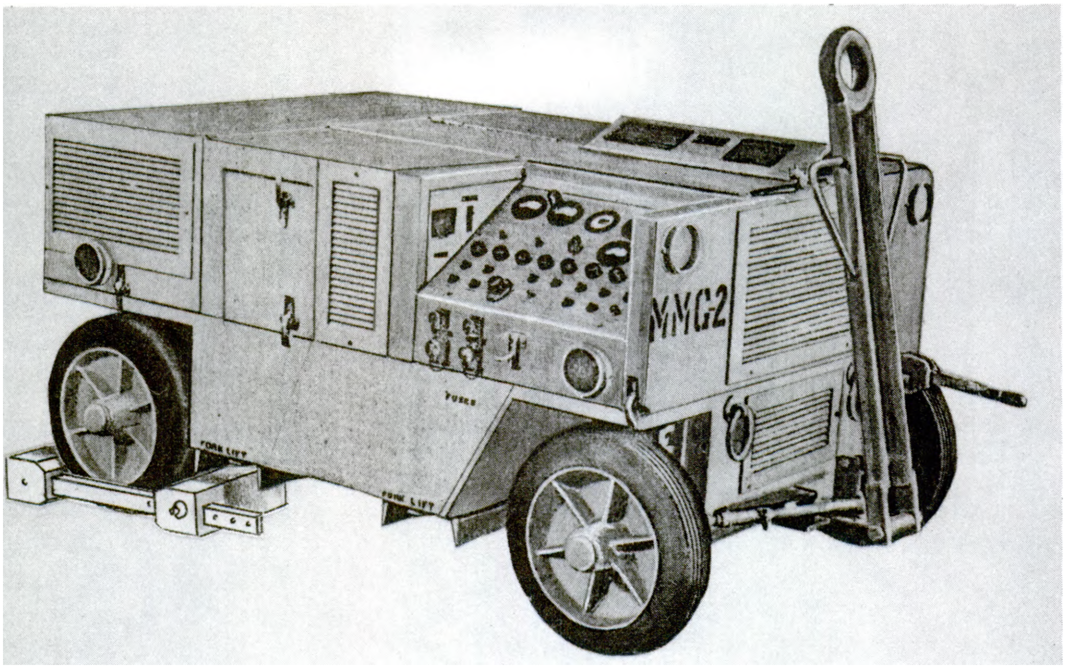

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Figure 5-7.—MMG-2.

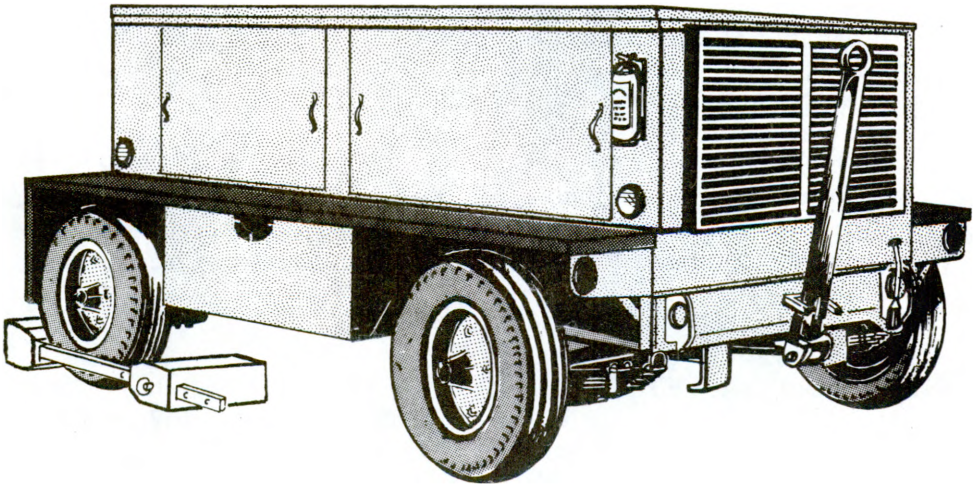

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Figure 5-8.—MMG RX-400.

208-volt ac line-to-line, or 28-volt dc at a maximum dc load of 2,000 amperes (either ac or dc but not both at the same time).

ADDITIONAL SUPPORT EQUIPMENT

DECKEDGE POWER

The primary function of the deckedge electrical power system installed on aircraft carriers is to provide a readily accessible source of servicing and starting power to aircraft at almost all locations on the carrier's flight and hangar decks.

The 28-volt dc is supplied by motor-generators, or rectified ac from remote ac generators.

The 400-Hz, 3-phase ac servicing voltage is usually supplied by these ac generators through stepdown transformers. Figure 5-9 shows a location diagram of an electrical system which may be found on a modern carrier. The deckedge power may be supplied by service outlets at the edge of the flight deck or from recesses in the flight deck. All systems have standard remote control switches, service outlet boxes, and portable cables. Figure 5-10 shows a typical deckedge installation.

The dc service outlet box contains two male plugs. One is rectangular in shape and the other is oval. The rectangular plug provides servicing power and the oval provides starting power for aircraft with electrical starters.

The aircraft is equipped with an oval-shaped receptacle for applying dc servicing power and a rectangular-shaped 6-pin receptacle for applying 3-phase, 400-Hz, ac servicing power. Power is applied to the aircraft by connecting the portable cables between the deckedge and aircraft plugs. To obtain dc servicing power, the oval edge of the portable cable is connected to the oval plug in the aircraft, and the rectangular end is connected to the dc service power box rectangular plug.

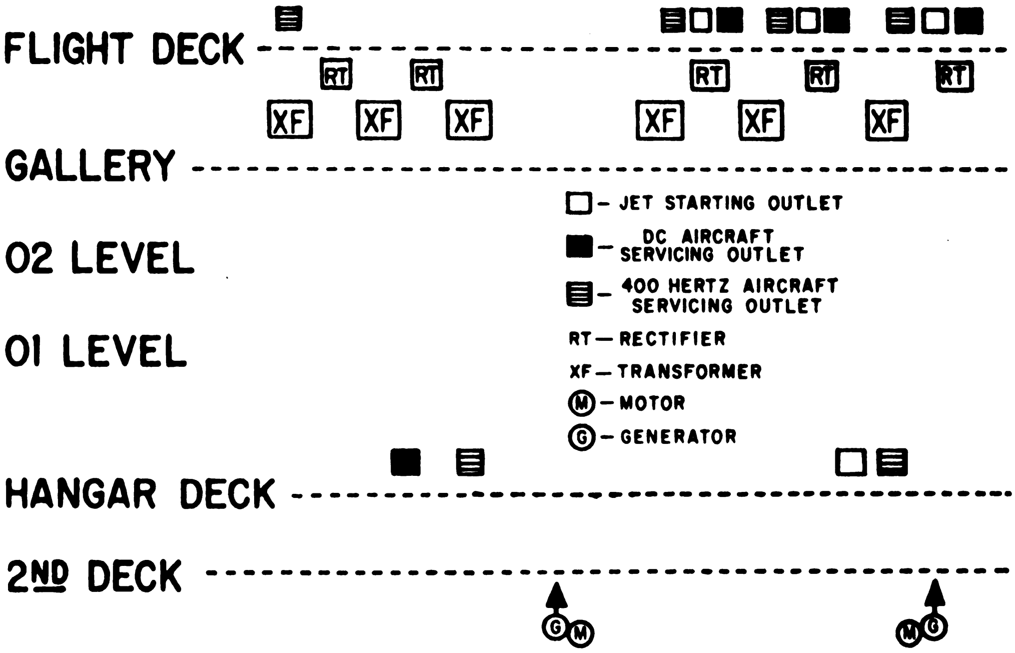

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Figure 5-9.—Deckedge electrical system.

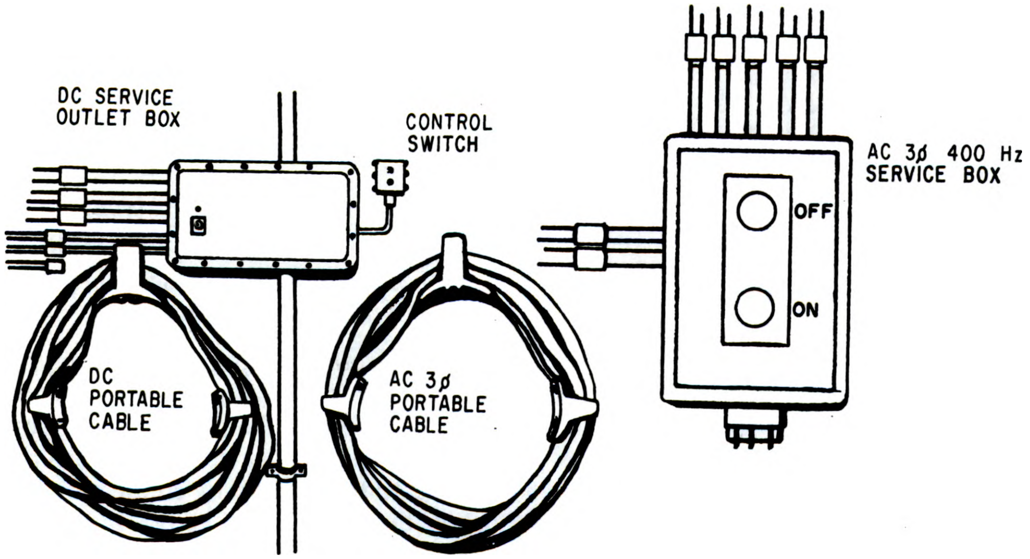

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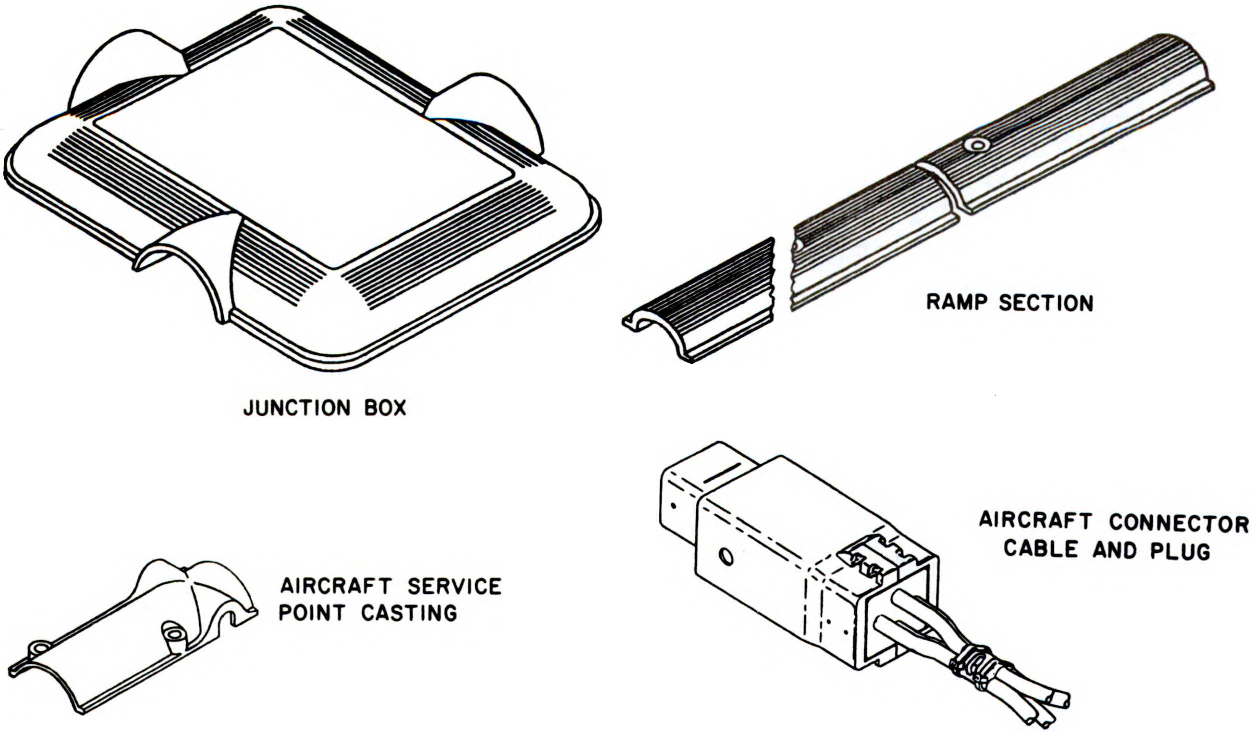
Figure 5-10.—Typical deckedge installation.


JUNCTION BOX
RAMP SECTION
AIRCRAFT SERVICE POINT CASTING
AIRCRAFT CONNECTOR CABLE AND PLUG

227.113

Figure 5-11.—Major components of FLEDS.

To obtain 3-phase, 400-Hz, ac service power, the portable cable with the 6-pin rectangular shaped plugs is connected to the aircraft and the deckedge ac service power box. The ends of this portable cable are interchangeable.

The ac service power is usually provided at the same station as the dc power. The cable and plugs are the same type as those used on the NC-8A and NC-2A mobile power plants. The cable is usually permanently attached to the service outlet box. Although its plugs are rectangular, there is no danger of connecting them to the dc service box rectangular receptacle, as the size and number of pins are not the same.

Care should be exercised when connecting external power cables to the aircraft. The cables are heavy, and damage to the aircraft may result if there is not sufficient slack in the cables.

FLIGHT LINE ELECTRICAL DISTRIBUTION SYSTEM (FLEDS)

The FLEDS is an electrical distribution system for servicing aircraft on the flight line. Figure 5-11 shows the major parts of the FLEDS. It consists of 3-way junction boxes, interconnecting ramps, aircraft service point castings, and aircraft connector plug assemblies. The total system capability is 24 aircraft (fig. 5-12). Each service point can service one aircraft with 115/200 volts, 3-phase, 400-Hz power.

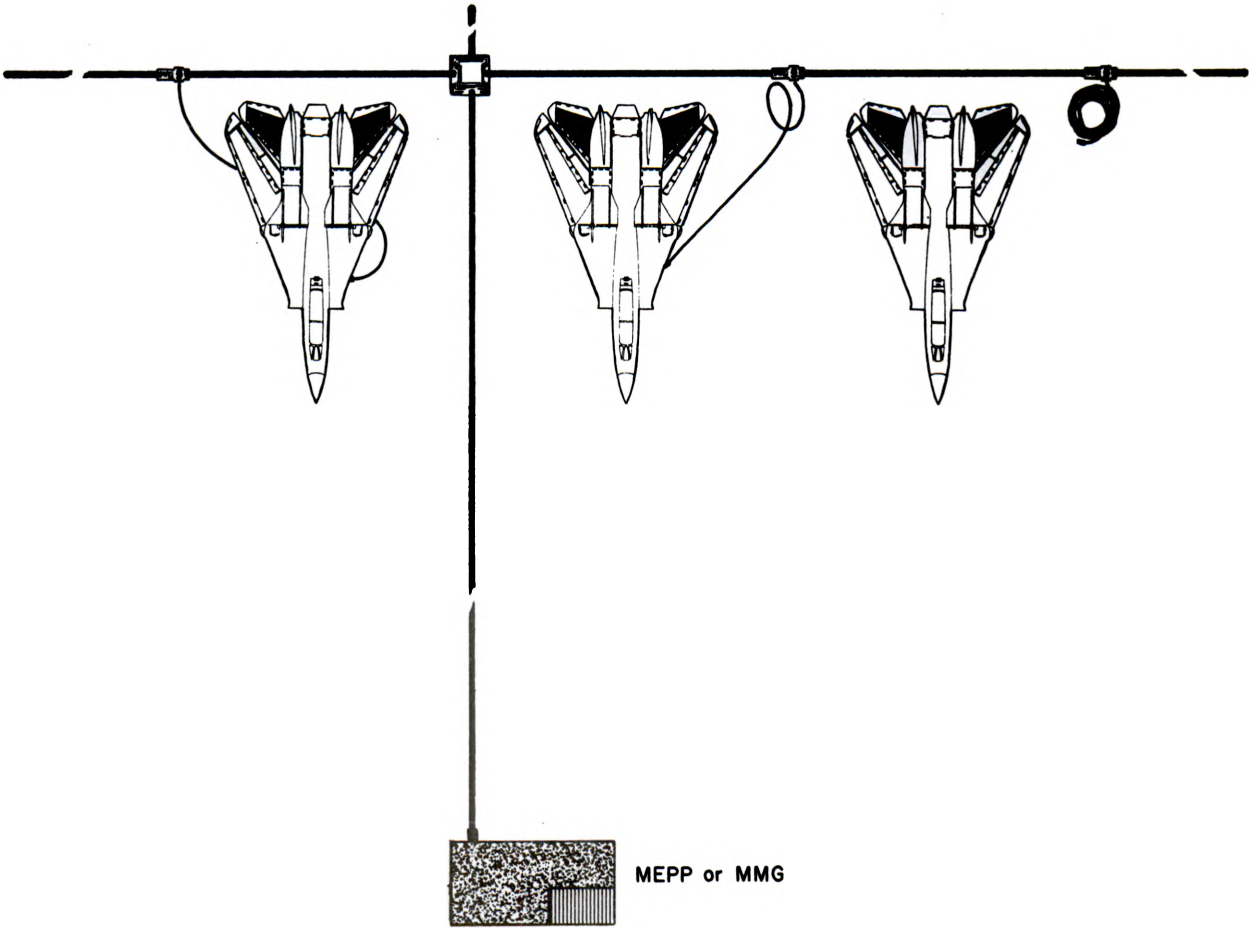


Figure 5-12.—FLEDS.

The FLEDS accepts power from a Mobile Electrical Power Plant (MEPP) capable of supplying 115/200-volts, 3-phase, 400-Hz power. Power is applied at the junction boxes and branches into the service point castings to the aircraft connector plug assemblies. The cables connecting the junction boxes, service point castings, and aircraft connector plugs are installed underneath the interconnecting ramps for protection.

NR-5C AIR CONDITIONER

The NR-5C air conditioner (fig. 5-13) is a mobile, trailer-mounted unit and is electric-powered by a 30-horsepower, 440-volt, 3-phase, 60-cycle electric motor which is an integral part of the compressor.

The unit is mounted on four wheels. The two rear wheels are nonsteerable, shock-absorbing on heavy duty cushion tread tires. Two swivel shock-absorbing wheels are provided on the center front of the unit. The rear wheels incorporate parking brakes that are applied or released by a single manual control lever located at the front of the unit. Access doors and panels are provided for full accessibility. Four lifting rings are mounted on the upper corners of the unit.

NR-10 AIR CONDITIONER

The NR-10 air conditioner (fig. 5-14) is also a mobile, trailer-mounted, self-contained air-conditioning unit. A six-cylinder, turbocharged, 82-horsepower diesel engine supplies all the power for the operation of the air conditioner. Incorporated in the engine are a manual throttle, water pump and thermostat, oil filter, fuel injection pump, fuel transfer pump, fuel filters, variable speed governor, overspeed control, thermal protection and low oil pressure safety switches, generator, and starting circuits.

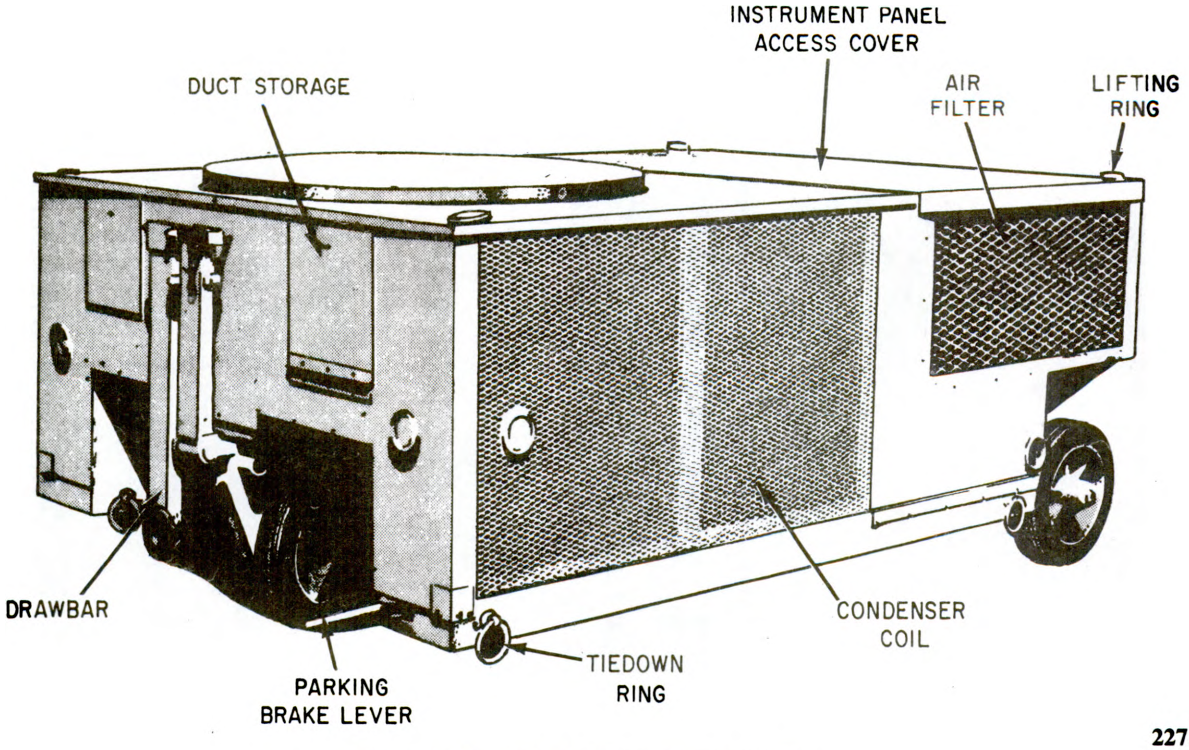


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Figure 5-13.—NR-5C air conditioning unit.

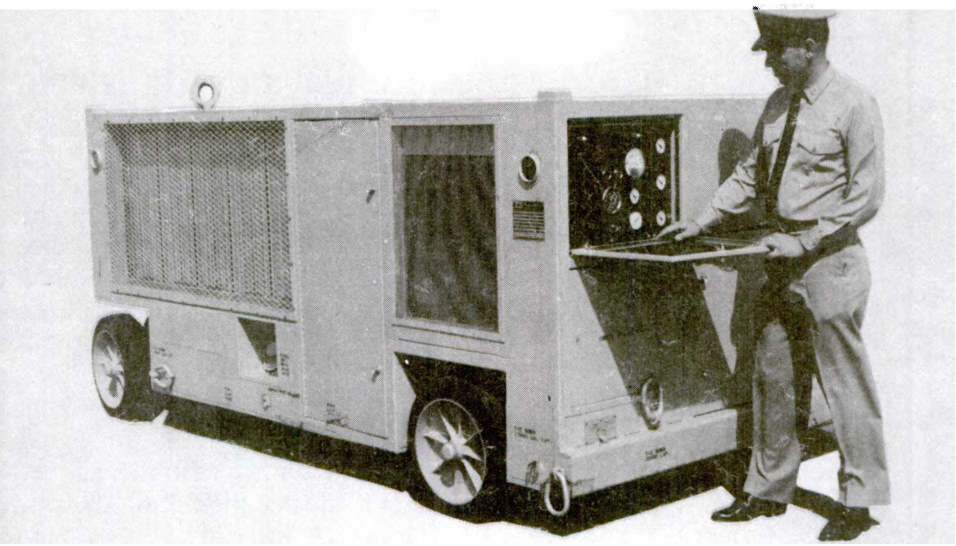

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Figure 5-14.—NR-10 air conditioner.

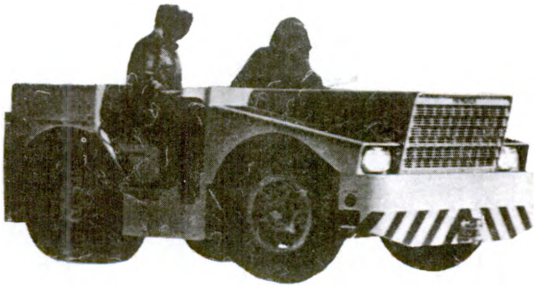

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Figure 5-15.—TA-18 tow tractor.

The engine is liquid-cooled by means of a radiator. Air flow through the radiator is provided by the condenser fan. The axle assembly consists of the tow bar and four independent suspension wheels. The tow bar assembly is designed so that when the front wheels attain their maximum angular position, a cam on the tow bar assembly is released allowing the tow bar to continue following the motion of the towing vehicle. All four wheels are provided with braking.

TA-18 TOW TRACTOR

This is a gasoline powered tractor for use on shore bases as an aircraft towing and spotting vehicle for large aircraft. This tractor has a drawbar pull of 18,000 pounds.

The TA-18, shown in figure 5-15 has an automatic transmission with six forward speeds and one reverse speed. The speed ranges are selected by a shift lever located on top of the transmission cover. The transmission shift pattern is shown in figure 5-16. The tractor dimensions are 14 feet 10 inches long, 8 feet wide, and 5 feet 7 inches high. The turning radius is 24 feet 10 inches. The gross weight of this tractor is 25,800 pounds. Normally, the driver's compartment is open, as shown in figure 5-15, but if the tractor is to be used in arctic weather, a completely enclosed cab is

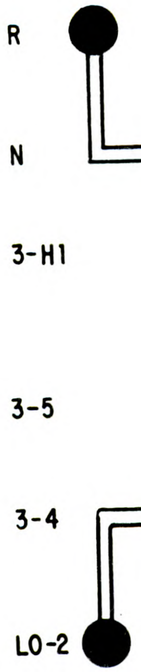

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Figure 5-16.—TA-18 transmission shift pattern.

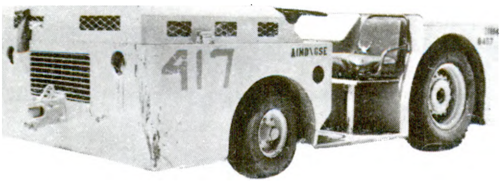

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Figure 5-17.—TA-75 A/B tow tractor.

available. These cabs are equipped with windshield wipers, a heater, and a defroster.

TA-75A/B TOW TRACTOR

The TA-75A/B is a gasoline-powered tractor intended for use on shore bases as a towing and spotting vehicle for aircraft with gross weights up to 75,000 pounds.

The TA-75A/B (fig. 5-17) has provisions for mounting a gas turbine compressor or other servicing equipment. This add-on provision has not been widely used. The tractor is equipped with an automatic transmission that has three forward speeds and one reverse speed. The tractor dimensions are 20′3″ long, 5′6″ wide, and 3′2″ high. The turning radius is a minimum of 140″.

A/S 32A-30 AIRCRAFT SUPPORT EQUIPMENT TRACTOR

The A/S 32 tractor (fig. 5-18) is designed to tow mobile support equipment such as starting units, work stands, electrical power plants, hydraulic test stands, and other SE. It has a towing capacity of approximately 4,000-pound drawbar pull and can also be used to tow armament handling equipment. As a secondary mission, it can be used to tow light aircraft and helicopters.

The tractor is a gasoline engine-powered unit with a Chrysler model A-727 automatic transmission. It is a shore based tractor to be used on concrete or asphalt surfaces in support of aircraft operations. Hydraulic brakes are on both front and rear wheels and it has power assist steering. At the time of this writing there have been two separate contracts to manufacture the A/S 32 tractor.

AIRCRAFT TOW BARS

Two general classes of tow bars are used in naval aviation: those adaptable to only one type of aircraft and those adaptable to more than one type of aircraft. Most naval aircraft may be towed with the Universal Aircraft Tow Bar, Model NT-4, shown in figure 5-19. The tubing of this tow bar is aluminum alloy. The tow hitch plate, end hooks used in forward towing, and the pins that fit into the hollow axle of the tail wheel and nose wheel are steel. The aluminum wheel well casting is bushed to take the towing pins when changing from nose wheel to tail wheel towing and vice versa.

For forward towing of aircraft not having a nose wheel, the end hooks of the tow bar are placed through the main landing gear towing rings. The hooks are held in place by spring loaded lock pins. When towing aft from the hollow axle of the tail wheel, the towing pins on the wheel well casting are placed in the tail wheel

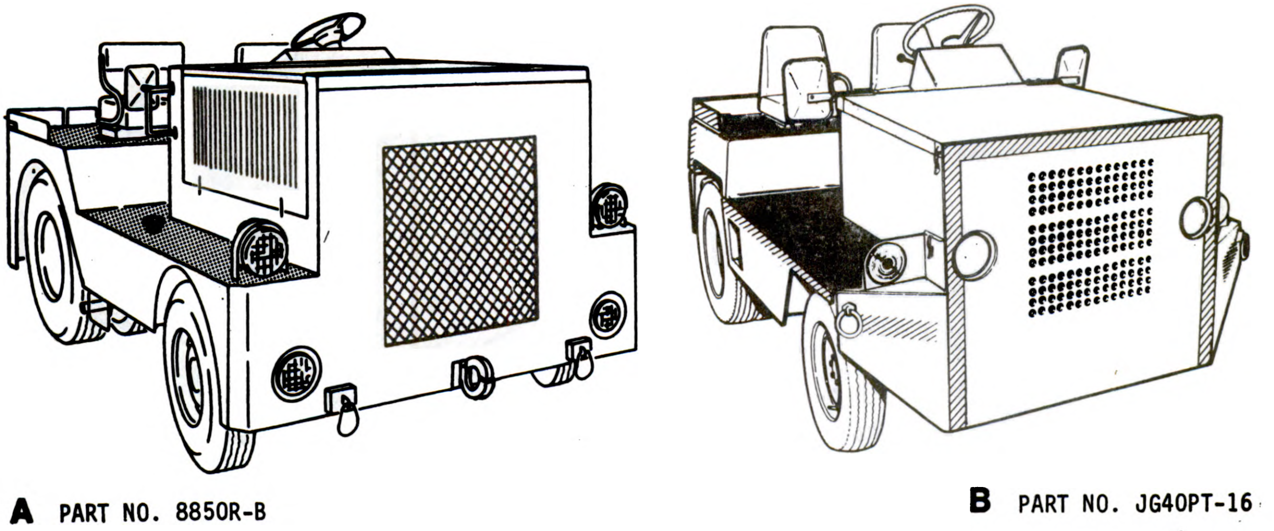

Figure 5-18.—Aircraft support equipment tractors, Type A/S 32A-30.

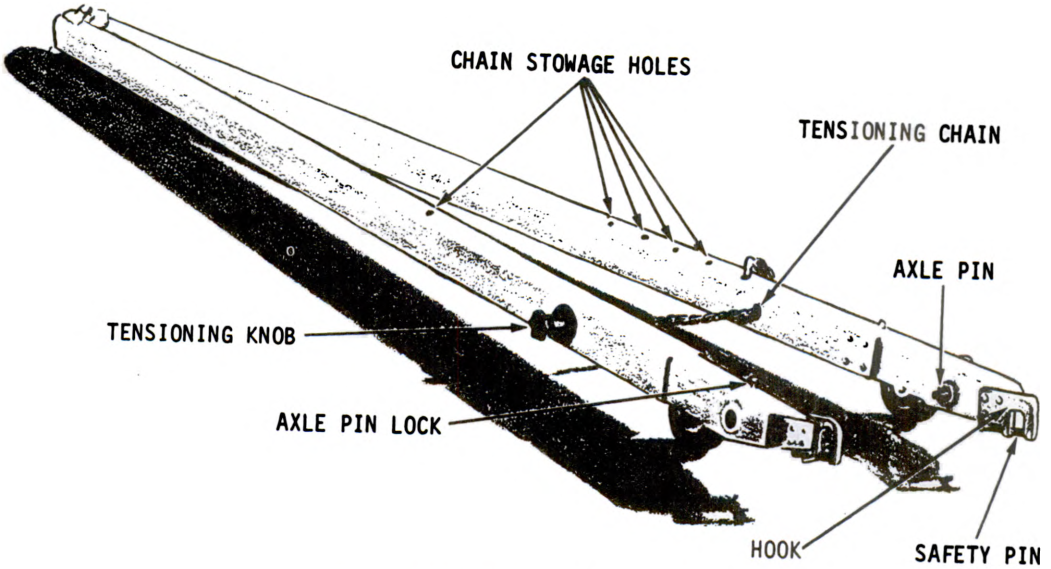

Figure 5-19.—Universal front and rear tow bar.

axle on each side. They are then clamped in place by a chain that slides through a sleeve and is tensioned by turning a knob. A similar procedure is used in towing certain aircraft from the nose wheel; however, the towing pins are removed from the wheel wells and reversed. On other aircraft the end hooks of the tow bar are placed through the towing rings of the nose wheel and locked in place by the spring loaded lock pins provided for this purpose.

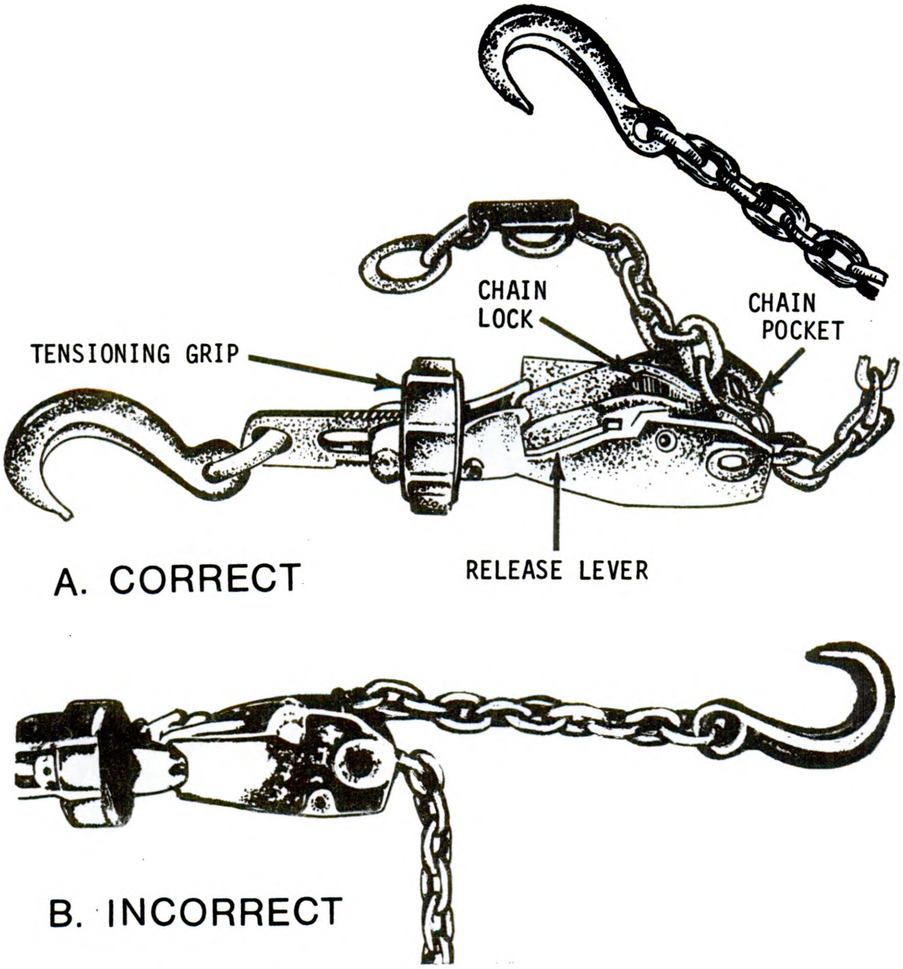

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Figure 5-20.—TD-1A tiedown chain installation. A. Correct, B. Incorrect.

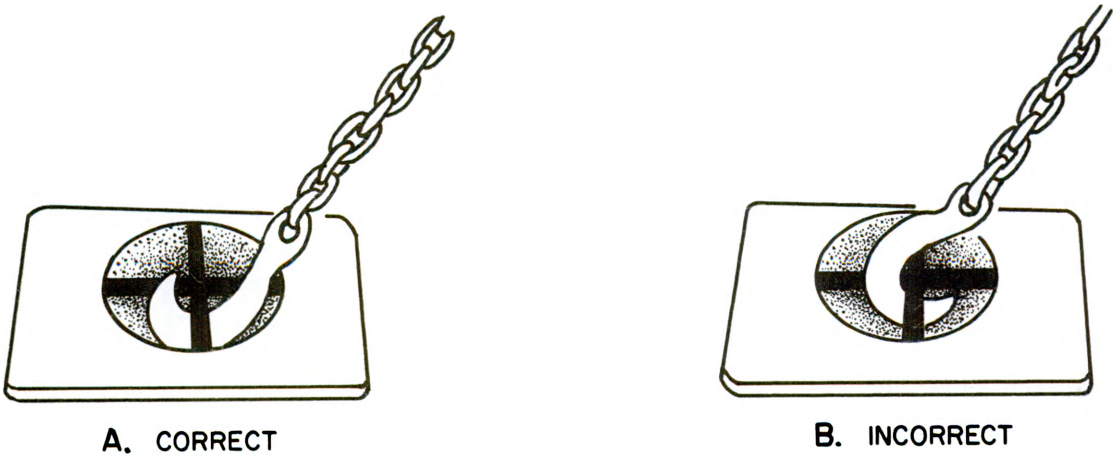

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Figure 5-21.—TD-1A hook installation. A. Correct, B. Incorrect.

Certain aircraft may be satisfactorily towed only by the use of a tow bar designed specifically for them. For the proper use of such tow bars, consult the manufacturer's instructions for that particular aircraft.

TIEDOWNS

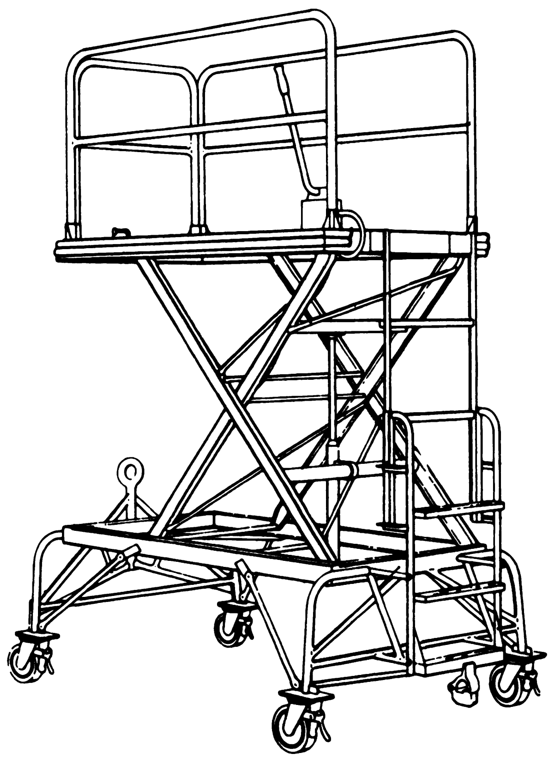
The TD-1A all-purpose tiedown (fig. 5-20) is most commonly used by the Navy for securing parked aircraft and support equipment. The ease and speed with which it can be attached to or removed from aircraft and equipment make it most desirable during flight operations aboard carriers, when time is vital.

In "A" of figure 5-20, the correct placement and relationship of the chain in the tiedown head is illustrated. The axis of the chain/hook assembly is in alignment with the centerline of the head. In this position, the TD-1A (which has a 10,000-pound rated working capacity) would fail at a load of 16,000 pounds. Incorrect installation is shown in "B" of figure 5-20. The chain/hook assembly does NOT pull in line with the centerline of the head. Destructive pull test data shows that with the chain in this improper position, failure occurs at loads ranging from 4,200 to 6,850 pounds, with failure occurring at the serrated chain locking arm (chainlock). From these figures, you can note that improper chain installation reduces the tiedown holding strength by two-thirds of its former strength. This is an excellent reason for appropriate care to be taken in assembling this tiedown.

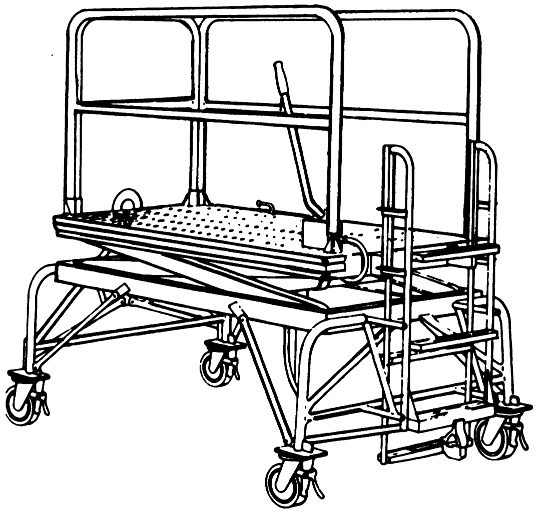
Another common error in the use of the TD-1A is incorrectly placing the chain hook into the padeye securing point. As shown in "A" of figure 5-21, the hook should be inserted with the point UP, versus the incorrect insertion as shown in "B" of figure 5-21. When properly installed, considerably more slack in the chain is required before the hook accidentally becomes disengaged from the padeye.

MAINTENANCE PLATFORMS (WORKSTANDS)

The B-4A adjustable maintenance platform (fig. 5-22) is a hydraulically operated platform and ladder assembly, mounted on a castor-equipped base, which enables personnel to work



RAISED



LOWERED

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Figure 5-22.—B-4A adjustable maintenance platform.

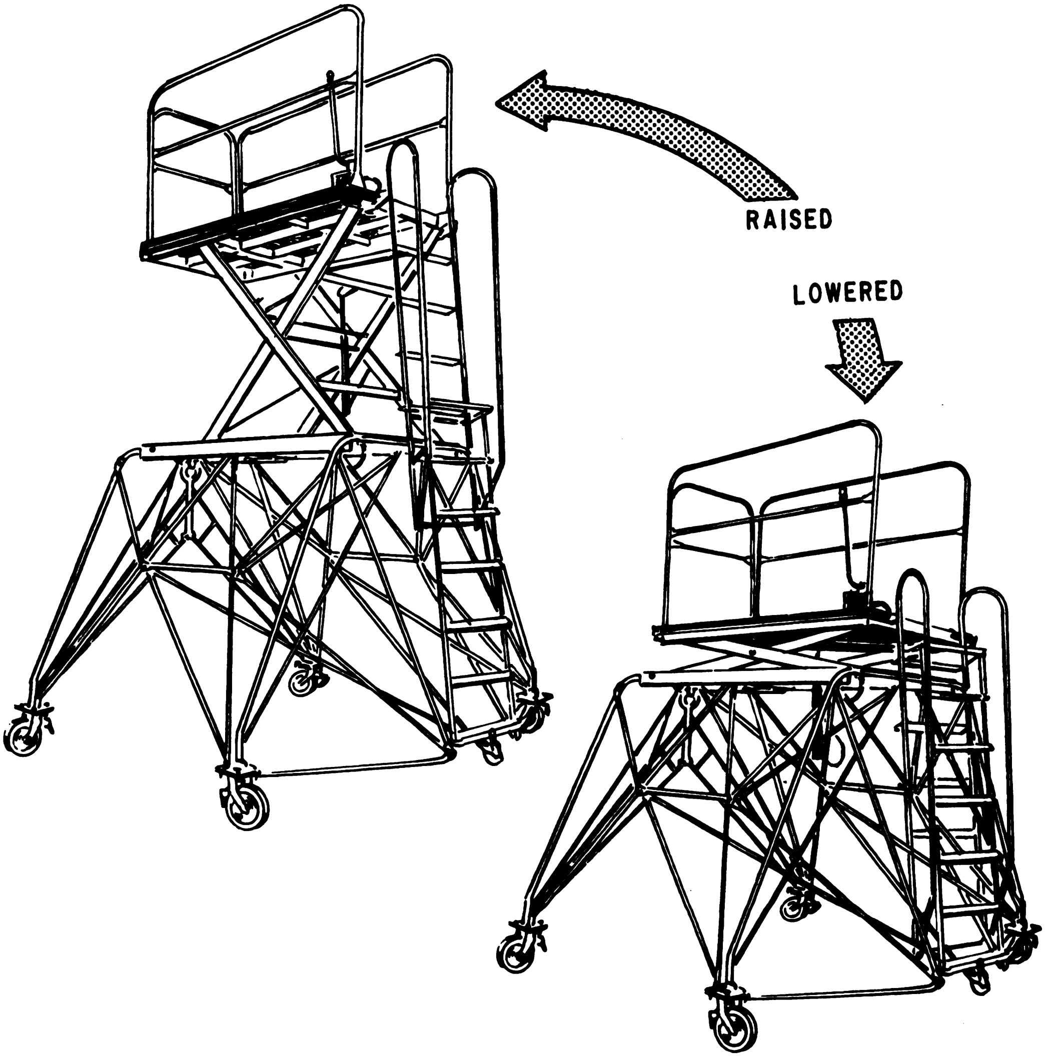

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Figure 5-23.—B-5A adjustable maintenance platform.

in safety at heights varying from a minimum of 3 feet to a maximum of 7 feet. All four wheels have locks to make the platform stationary, and safety pins to hold the platform in position once it is raised.

The B-5A adjustable maintenance platform, shown in figure 5-23 is similar to the B-4A maintenance platform, but the base on the B-5A is larger and tapers toward the top. Likewise, the ladder is designed differently and is longer. The minimum height of the B-5A is 7 feet, and the maximum height is 12 feet.

There are other types of maintenance platforms in use, but the ones already mentioned are the types with which you are most likely to come in contact.

P-36 AIRFIELD MAINTENANCE TRUCK

The P-36 airfield maintenance truck (fig. 5-24) is a platform truck capable of hauling loads up to 3,600 lb. A 34-horsepower, four-cylinder, air-cooled engine provides the power.

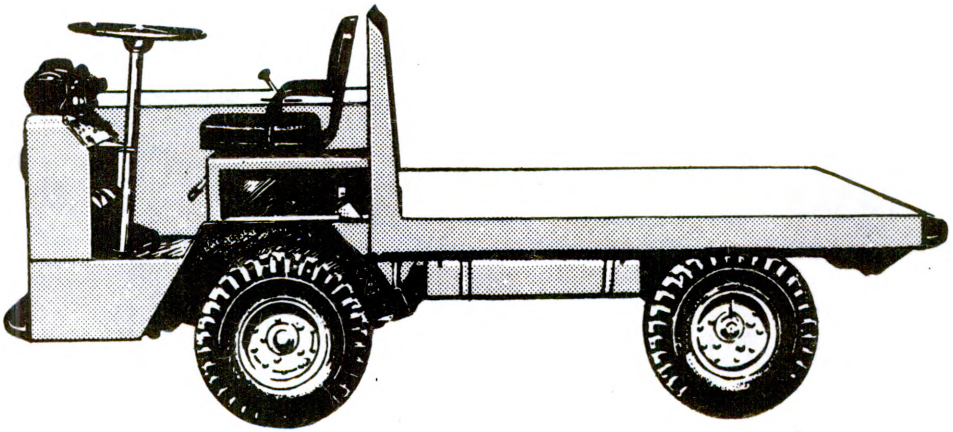

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Figure 5-24.—P-36 airfield maintenance truck.

The open operator's compartment is located at the front of the truck beside the engine. The transmission and steering are manually operated. The ignition system is the coil and distributor type. The maximum governed speed of the engine is 2,175 rpm producing a top speed of 15 mph. Hydraulically operated brake shoes inside each wheel brake drum provide a means of braking the truck. The standard shift transmission unit provides two forward speeds and one reverse speed. The six-volt lead acid storage battery, generator, and voltage regulator system is the source of power for the starting, ignition, and lighting systems.

This truck is used around airfields for general hauling. It can be used for off-paved surface hauling at low speeds but has only a five-inch clearance. It is provided with a coupler on the rear of the frame to facilitate towing trailers or other vehicles.

BOMB HOIST AERO 14C

The Aero 14C hoist (fig. 5-25) is a crank-operated, single-cable device for hoisting loads. It is the current replacement for obsolescent hoists. It consists of a gear train, drum and cable, brake mechanism, fishpole-type extension tube, and two handcranks, a ratchet crank and a brake crank. The cranks turn in the opposite direction from drum rotation. The ratchet crank is used only to help lift the load and may be disengaged from the gear train by latching a ratchet pawl with a ratchet pawl latch. The brake crank is used to lift the load and to control the position of the load. After the load is lifted, a clutch type brake holds the gear train fast. Backing off the brake crank lowers the load, but only as long as the brake crank is turned backward.

A spring-loaded roller, riding on top of the cable drum, and a cable guide, inside the extension tube, keep the cable lying firmly in its groove even when no load is applied to the hoist. However, tension should always be maintained on the hoisting cable whenever the cranks are operated. A swiveling clevis for hook suspension, or the pulley trunnions at the end of the extension tube, couples the hoist to the bomb rack and permits the hoist to be operated from different points on the ground. The tube clamp permits the housing to be rotated to any position with respect to the extension tube.

The Aero 14C hoist has a 2,240-pound (1,016 kg) capacity with a 10-foot (3 m) lift height and weighs 54 pounds (24.5 kg).

GENERAL SAFETY SUPPORT EQUIPMENT

Safety around aviation support equipment is largely a matter of common sense and of not

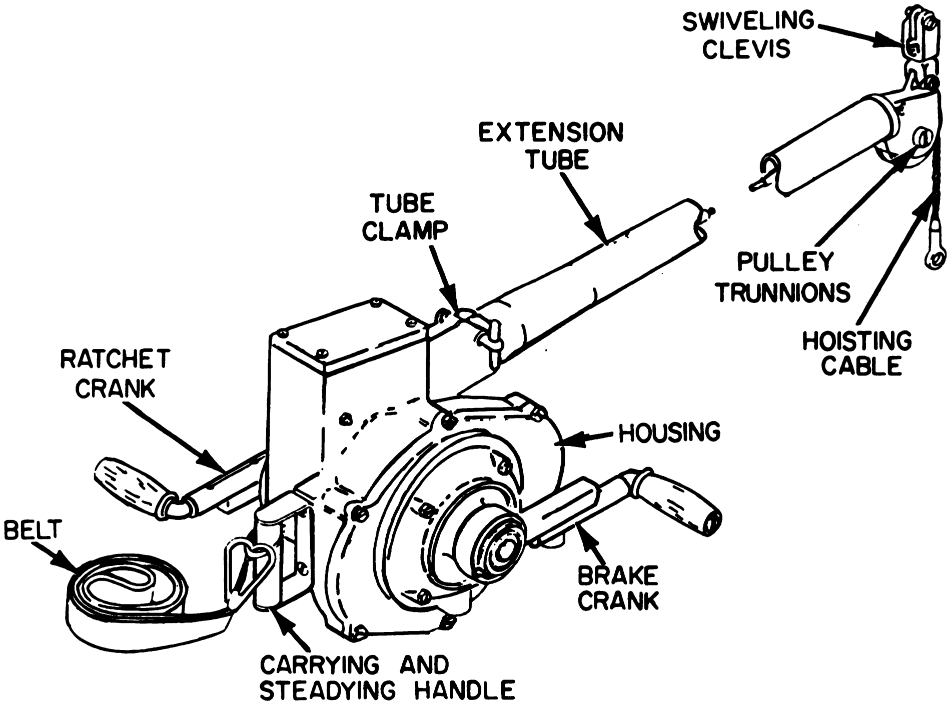

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Figure 5-25.—Bomb Hoist Aero 14C.

being in too big a hurry. You must take the time to perform the required safety measures. Common sense dictates what measures you should take to make your work around aviation support equipment as safe as possible. The full cooperation of everyone working with and around aviation support equipment is required, and all personnel must maintain constant vigilance to eliminate unsafe practices.

Safety requires that everyone must strictly observe all safety precautions applicable to the work. You and all workers concerned should report to the supervisor any unsafe condition, material, or equipment; warn others who appear to be endangered by hazards or by failure to observe safety precautions; and report any injury or evidence of impaired health that occurs to you or to others. Each worker should wear or use protective clothing or equipment prescribed for the safe performance of the work being done. When a hazardous condition occurs, each person should exercise as much caution as is possible under the existing conditions.

Some of the safety measures that should be used around aviation support equipment are covered in the following paragraphs:

- When stopping self-propelled equipment, set the handbrake or chock the vehicle. This should be done to towed equipment before unhooking.

- When mobile equipment is hand pushed or pulled, it should be done only when the engine of the vehicle is stopped, and the drive train or transmission is disengaged.

- Aboard aircraft carriers, any aviation support equipment that is not in use should be tied down to prevent it from becoming a hazard to personnel or equipment due to tight turning or tilting of the ship. All equipment should be as clean as possible to prevent accumulation of fuel, oil, hydraulic fluid, or grease from becoming a fire hazard or causing those who are working with or on the equipment to slip and fall.

- Each piece of aviation support equipment should be used only for the purpose for which it was manufactured, except in an emergency. It should be used only by authorized personnel. The authorization should be in writing and indicate that the holder has been thoroughly checked out in the operation of the equipment and the safety practices associated with it.

This chapter described a number of support equipments which you will encounter in your work as an aviation technician. It is important that you have knowledge of this equipment so you will know what to expect from it and will be aware of its limitations and safety requirements.

CHAPTER 6

REFLECTOMETRY TEST SETS

Multipurpose test equipment is discussed in Chapter 9 of *Avionics Technician 3 & 2,* Part 1. Unlike that equipment, reflectometry test sets are designed primarily to aid organizational maintenance technicians in verifying and troubleshooting aircraft wiring, transmission lines, waveguides, and antenna systems. They can, however, be used by intermediate maintenance technicians to verify cable connectors, to determine test cable impedances, and to troubleshoot test equipment.

The Navy presently uses two types of reflectometry test sets. They are time-domain reflectometer (TDR) and frequency-domain reflectometer (FDR) testers. In this chapter, we will discuss the theory of reflectometry testing and introduce two of the common testers in use. There are many models of reflectometer testers, but their basic functions are the same.

TIME-DOMAIN REFLECTOMETRY (TDR) TEST SETS

Time-domain reflectometry (TDR) test sets are used mainly to check/troubleshoot aircraft wiring, transmission lines, and antenna systems for shorts, opens, crimps, or bad couplings, etc. The TDR accomplishes these tasks by monitoring reflected waveforms. TDRs operate on the same principle as radar. That is, they send pulses of energy into a system to see what, if anything, is reflected. As with standing waves on an antenna line, if nothing is reflected, the impedance of the transmission line is uniform and properly terminated. But if crimps, opens, bad couplings, etc., are present, a discontinuity will exist and pulses in phase, or out of phase will return to the TDR test set and be displayed on its CRT as positive, negative, or simply fast-rising voltages, signifying known causes usually at fault. Impedances greater than 50 ohms are seen by the TDR as in phase, while those less than 50 ohms are seen as out of phase. These are respectively classified (traditionally) as inductive and capacitive faults, readily explained by the basic equation:

$Z_o = \sqrt{L/C}$. This, of course, specifies the equalities of inductance (L), capacitance (C), and impedance (Z).

TDR BASICS

The TDR analysis begins with the insertion of a step or pulse of energy (referred to as the "incident signal") into a system or cable and the subsequent observation, at the point of insertion, of the energy reflected by the system or cable under test. Figure 6-1 illustrates the typical TDR analysis. The output of the pulse generator is a step-signal with a rise time of approximately 110 picoseconds. This signal (incident signal) goes through a sampling tee to the CRT of the oscilloscope and to the system under test via a 50Ω termination connector. The equivalent bandwidth of the CRT deflection circuits provides a system rise time of approximately 140 picoseconds. This allows the TDR to give resolution (detect faults) as close as one-half inch apart. The reflected signal from the system under test reenters the TDR test set and returns via the sampling tee to the oscilloscope CRT along with the incident signal. By comparing the magnitude, duration, and shape of the reflected signal, the nature of the impedance variation in the system under test can be determined.

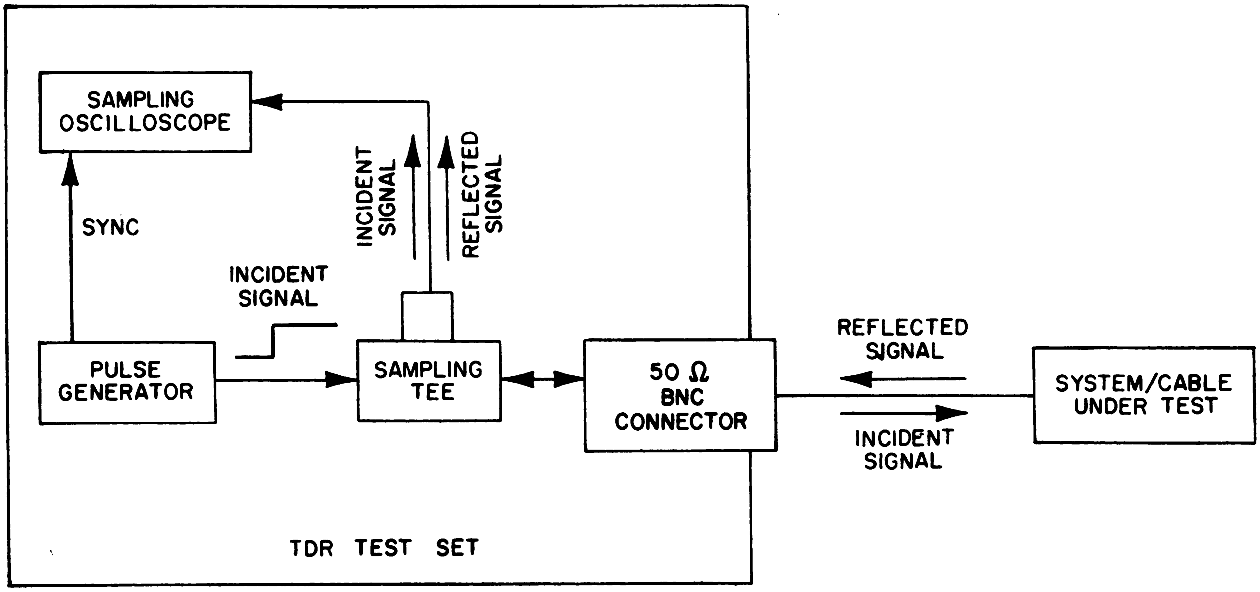

Figure 6-1.—Typical TDR analysis.

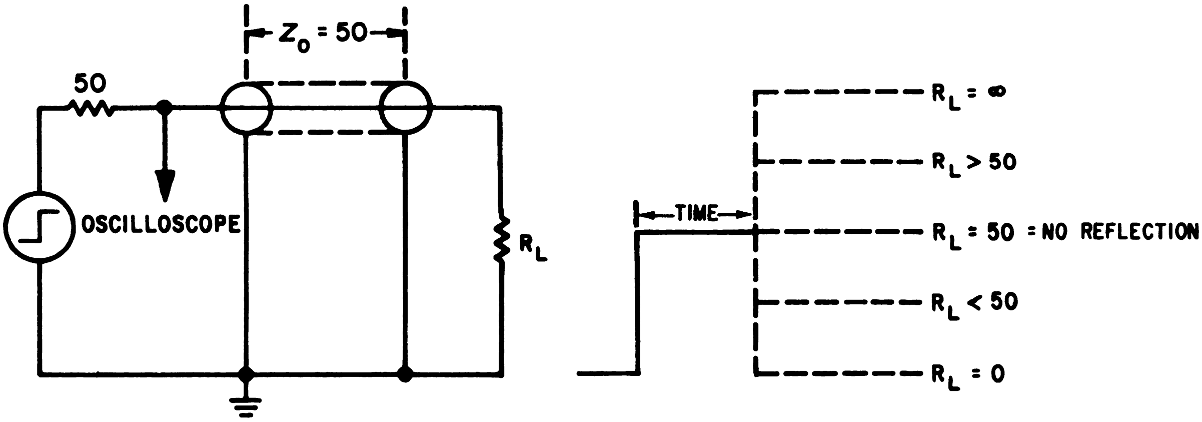

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Figure 6-2.—Step signal-height variations resulting from different resistive loads.

Resistive Loads

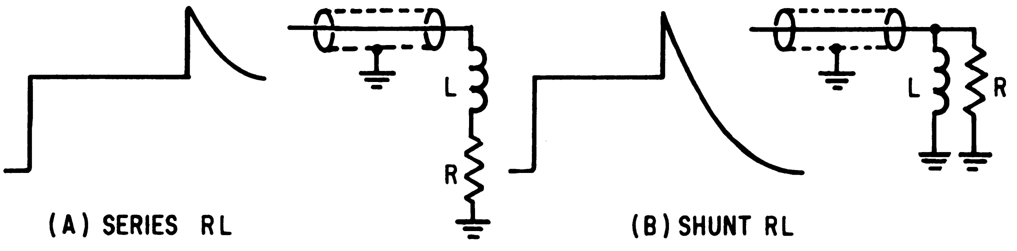
If a pure resistive load is placed on the output of the TDR, and a step signal is applied, a signal whose amplitude is a function of the resistance (see figure 6-2) is observed on the CRT. If the line is terminated in its characteristic impedance (Z_o) as shown in figure 6-2, there will be no reflected signal, and the signal observed on the CRT will remain flat. But if the impedance (R_L) at the termination is greater or less than Z_o, then reflections (standing-wave ratio [swr]) will exist. The amplitude of the reflected signal is proportional to the value of R_L. If R_L is greater than Z_o (50Ω), the reflected signal will be in phase with the incident signal; and when applied to the CRT, will add to the incident signal. If R_L is less than Z_o, the reflected signal will be out of phase with the incident signal; and when applied to the CRT, will subtract from the incident signal. The dotted lines in figure 6-2 represent various composite signals (incident ± reflected) that would be observed for various values of R_L. The time from the start of the incident (step) signal to the step created by the reflected signal, represents twice the distance to the discontinuity. That is, the time it took the incident step to reach the discontinuity and return. Most TDRs are calibrated to read this time in feet or inches to the discontinuity.

It is good practice to separate the system under test from the TDR test set by eight inches of 50-ohm cable. This moves the reflections away from the leading edge of the step (start of incident signal), to prevent overshoot and ringing from being superimposed on the observed CRT signal.

Reactive Loads

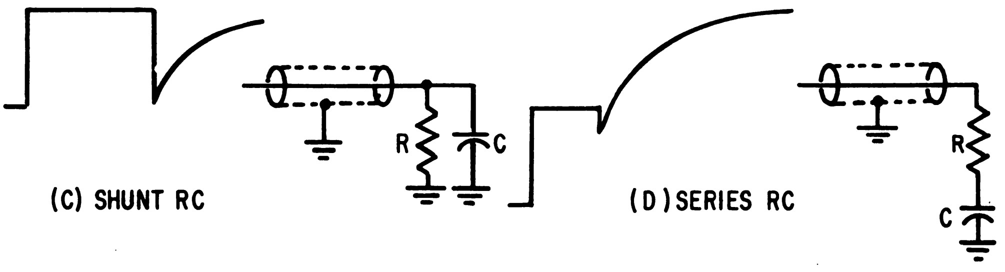
The waveform of reactive loads (figure 6-3) depends upon the time constant formed by the load and the 50-ohm source. The series RL network in (A) of figure 6-3 appears as an open the instant the step voltage reaches it, because the inductor L offers maximum impedance to the change in current caused by the step voltage. Therefore, the reflected signal is in phase with the step voltage and is additive. This explains the sharp rise in voltage. However, as soon as the inductor saturates, the only opposition to current is resistor R; and since L saturates at a nonlinear rate, the voltage drops at a nonlinear rate from the peak of the spike to the same level as the flat portion of the step voltage. At this time the only load seen by the line is the 50-ohm resistor, which is equal to the characteristic impedance of the line, and the reflections cease until the next step appears at the termination, and the cycle repeats itself.

You can understand the waveshape in figure 6-3 (B) by remembering that L appears as an open to the fast rising step voltage the instant it is felt at the termination. However, as the inductor saturates, it offers less and less opposition to current until it is completely saturated (0 ohm). Since the inductor is parallel



(A) SERIES RL

(B) SHUNT RL



(C) SHUNT RC

(D) SERIES RC

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Figure 6-3.—TDR reactive load characteristics (time constant = 1).

to R, the termination is a short, and the reflected wave is 180° out of phase with the incident wave. Since L saturates at a nonlinear rate, the voltage declines at a nonlinear rate. A similar analysis can be made of the transmission lines with the RC terminations shown in (C) and (D) of figure 6-3.

The analysis just made of the different types of discontinuities explains the usefulness of TDR. Not only can a discontinuity be determined, but through proper analysis you can determine whether it is resistive, inductive, or capacitive, and whether it is in series or parallel with the load.

TDR IN PRACTICE

TDR discontinuities are clearly separated in time on the CRT. It is easy to see the mismatch caused by a connector even if a bad discontinuity is present elsewhere in the system. By using the analysis explained previously, you can establish which connector is troublesome and in what way. Once you have determined that a discontinuity appears in a waveform, it is simple to locate it in the system. A timesaving way of doing this is to calibrate the system so that one centimeter on the horizontal axis is the equivalent of a certain number of feet for the transmission system under test. The limiting factor is the system rise time, and any closely spaced discontinuities will appear as a single discontinuity.

The finite rise time also limits the size of the distinguishable reactive impedance response. For example, a small shunt capacity in a 50-ohm system will cause the waveform to depart from the ideal response (figure 6-4).

The maximum observable line length is a function of the repetition rate chosen. This rate determines the duration of the pulse after its rise. For example, a 200-kHz repetition rate permits the use of TDR devices with up to 1,000 feet of air dielectric cable or 670 feet of polyethylene dielectric coaxial cable. The speed at which a wave travels through a transmission system is determined by the system's velocity constant; thus a wave travels faster through air than through polyethylene. This explains the difference in maximum lengths of coaxial cable that can be checked using a particular repetition rate on the TDR—the longer the cable, the lower the repetition rate must be.

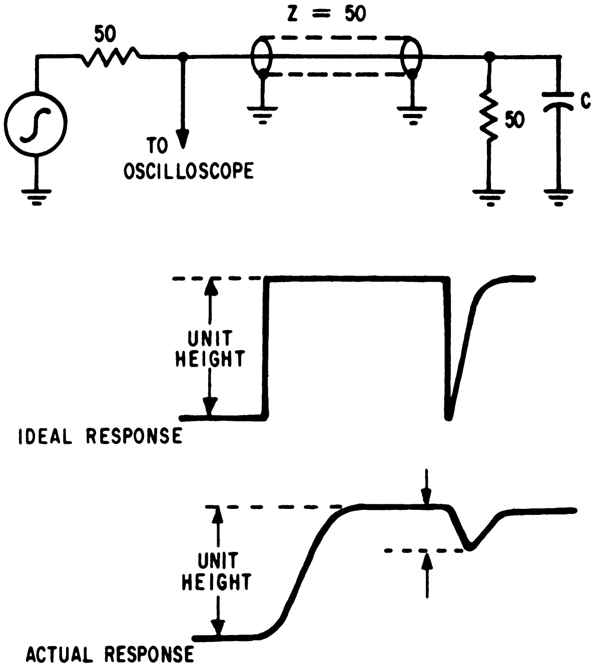

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Figure 6-4.—Small shunt capacity in system degrades ideal response.

RANGE AND RESOLUTION

Assuming that the total impedance (Z_o) equals 50 ohms, a resistance between 0.025 ohms and 100 kilohms may be measured. Because the height of the reflection is directly proportional to the resistance encountered, the resistance may be determined by the use of a precalculated transparent overlay.

One common use of TDR is in analyzing a coaxial cable. The amount of impedance variation that can be detected in a long section of cable is a function of the flatness of the top of the incident step. If this step is flat within ± one-half percent, impedance variation of one-half ohm along the cable can be detected, corresponding to a one percent check on cable impedance. Thus, irregularities in cable makeup resulting from variations in the braiding process or tightness of the insulating jacket show up clearly.

ANALYZING TERMINATIONS

Departure from 50 ohms in a termination or cable connector can cause large reflections in a pulse system or a large voltage standing-wave ratio (VSWR) in a system that carries primarily sinusoidal signals. Because of human errors in the assembly process, even the best connectors unfortunately cause reflections or a varying VSWR. Expensive connectors, therefore, do not ensure freedom from unwanted reflections, but TDR helps locate unacceptable connectors by rapidly showing where the mismatches are, how bad they are, if they are resistive, capacitive, or inductive, and whether series or shunt. Figure 6-5 shows a step being propagated from a section of RG9A/U into a load. The connector on the load and the cable are the General Radio Type 874. Four different cases are shown with varying loads, thus illustrating how the connection and the load can be analyzed by use of the TDR. With different connectors and loads, the small mismatches (discontinuities) take on different impedance characteristics and the reflected signals change. This change is also reflected in the waveshape viewed on the oscilloscope. A comparison between these signals and those of a normal system can be made by using an overlay showing the pattern of a normal system.

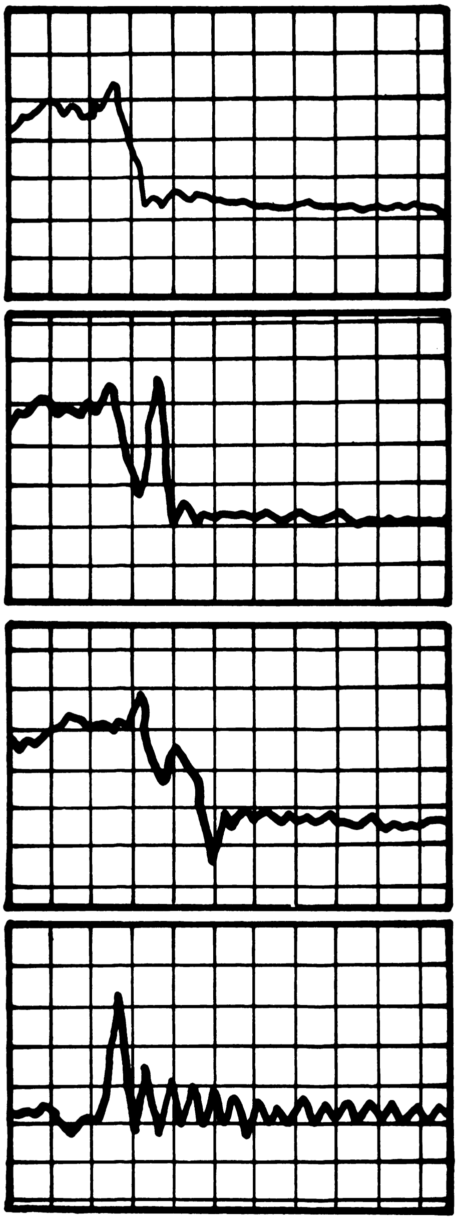

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Figure 6-5.—Waveforms resulting from the use of different loads. Horizontal scale μ 0.4 sec/cm; vertical scale 0.5 percent/cm.

Cable Impedance

The most convenient method of reflectometer use in making precise measurements of cable impedance is to connect a section of air dielectric line (with precisely determined impedance) between the test cable and the TDR unit. The step height through the air dielectric line section sets the 50-ohm level. Variations from this level in the test cable are noted, and the impedance of the cable is calculated (figure 6-6).

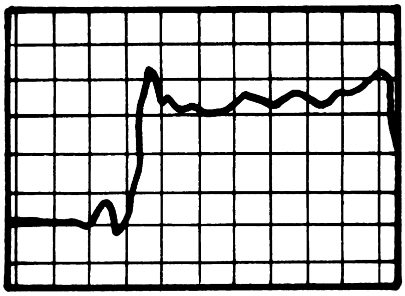

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Figure 6-6.—Oscillograph of step from air dielectric line into test cable.

In this test, the impedance level of the test line is:

$$Z_o = 50\frac{1+\rho}{1-\rho}$$

where ρ is the reflection coefficient of the reflected mismatch. The change in amplitude shows ρ to be +0.03, so:

$$Z_o = 50\frac{1.03}{0.97} = 53 \text{ ohms}$$

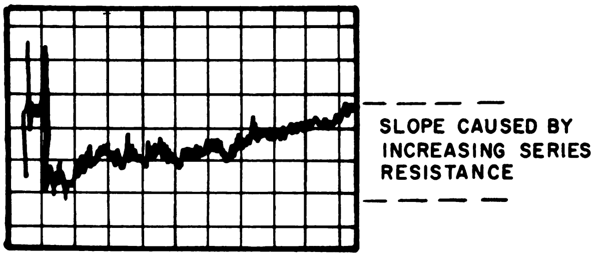

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Figure 6-7.—Trace of cable shows construction irregularities and increasing series resistance.

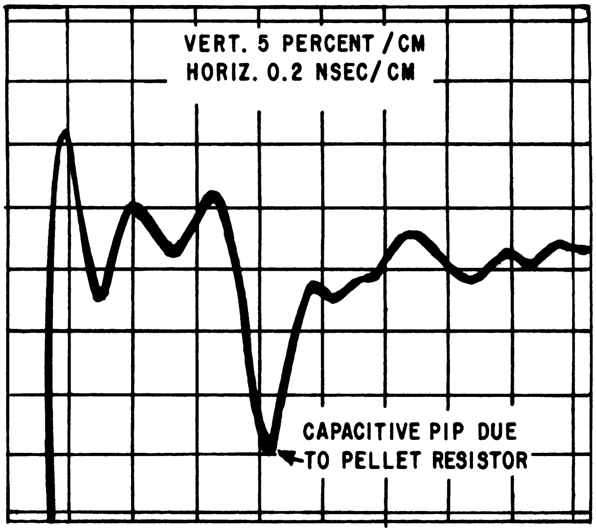

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Figure 6-8.—Resistor checked for shunt capacity with special jig.

The impedance of a long section of coaxial cable would be exactly Z_o if there were no line losses. However, most cables have a small series loss and a negligible shunt loss. This series resistance adds to Z_o, causing the impedance level, as observed at one end of a cable, to increase as longer sections of cable are added.

The slope on the step height that results from the increasing impedance is evident in figure 6-7.

Other applications in which the TDR method of analysis can be used effectively are component characteristic analysis and antenna analysis. The components can be placed in an appropriate jig and the TDR method used to determine their shunt capacity and series inductance (figure 6-8).

Investigation of antennas will reveal that the TDR pattern is not simple, but instead presents a complex reactive profile (figure 6-9). Once you determine the proper profile for a particular antenna, you can detect any improper construction details and ascertain the proper corrective action.

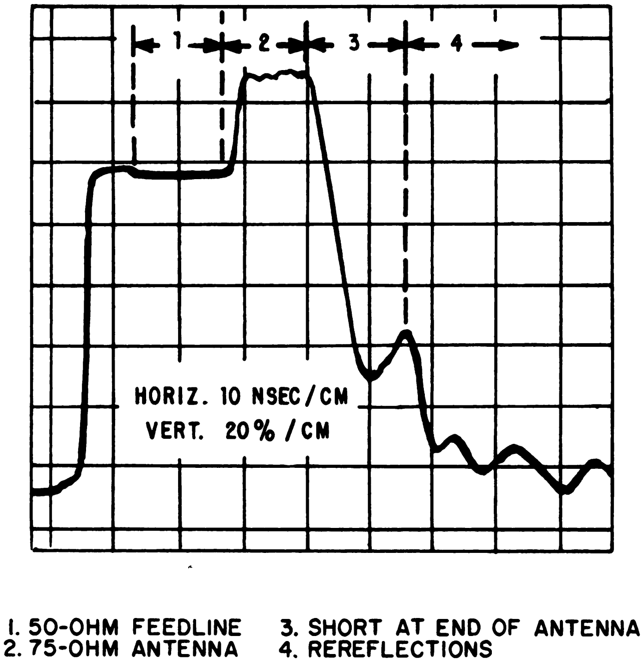

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Figure 6-9.—Scope trace of antenna reactive profile.

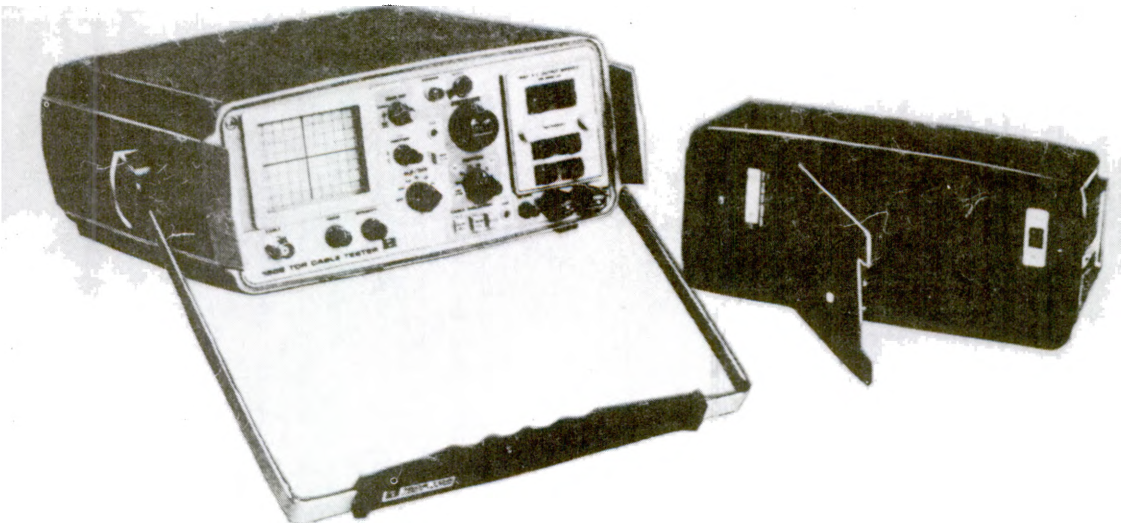

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Figure 6-10.—1502 Time-domain reflectometer.

TEKTRONIX 1502 TDR TESTER

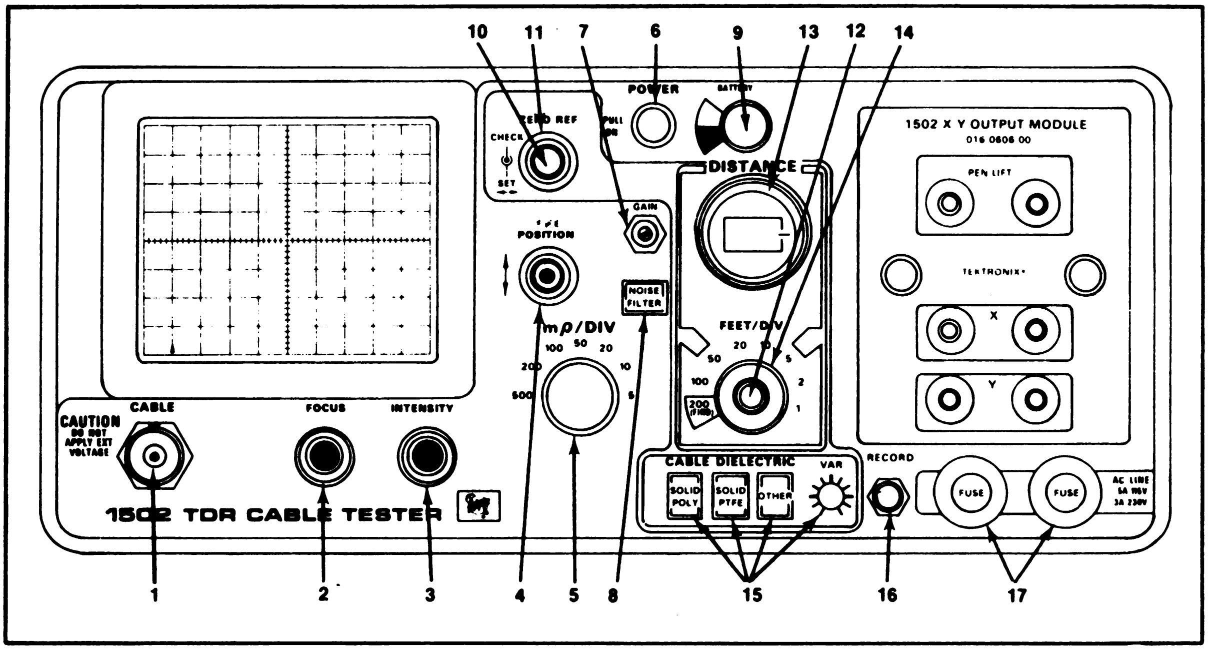
The Tektronix 1502 (see figure 6-10) is a portable, battery-powered TDR which uses radar principles to test cables and provides a visual CRT display of cable faults. It also has an output to drive a chart recorder if a permanent record of a test is required. The battery pack provides approximately five hours of operation of the equipment and is rechargeable. The equipment contains charging circuits for the battery pack. A three-pronged power cord is provided which, when plugged into a 115-volt ac source, will energize these charging circuits, and also allow operation of the tester while the battery is charging. It takes 14 to 16 hours to fully charge a discharged battery pack.

The output pulse of the 1502 is a step-signal with an amplitude of approximately 225 mV. The rise time of the pulse generator and the equivalent bandwidth of the deflection circuits provide a system reflected rise time of 140 picoseconds. The displayed rise time of the incident edge of the step signal is 110 picoseconds. Vertical deflection of the CRT beam is proportional to the amplitude of the reflected signal plus the incident step. The vertical scale on the face of the CRT (see figure 6-11) is calibrated in units of rho (ρ) of the transmitted pulse amplitude. The technical definition of rho (ρ) is resistivity, volume charge density, coordinates. On the 1502 TDR tester, rho is dependent on the characteristic impedance (Z_o) of the cable under test and the load (or the impedance of the discontinuity), R_L, on the cable. It can therefore be expressed as:

$$\rho = \frac{R_L - Z_o}{R_L + Z_o}$$

This relationship was used to develop a ρ versus impedance chart (figure 6-12), which is contained in the operator's handbook that comes with the equipment.

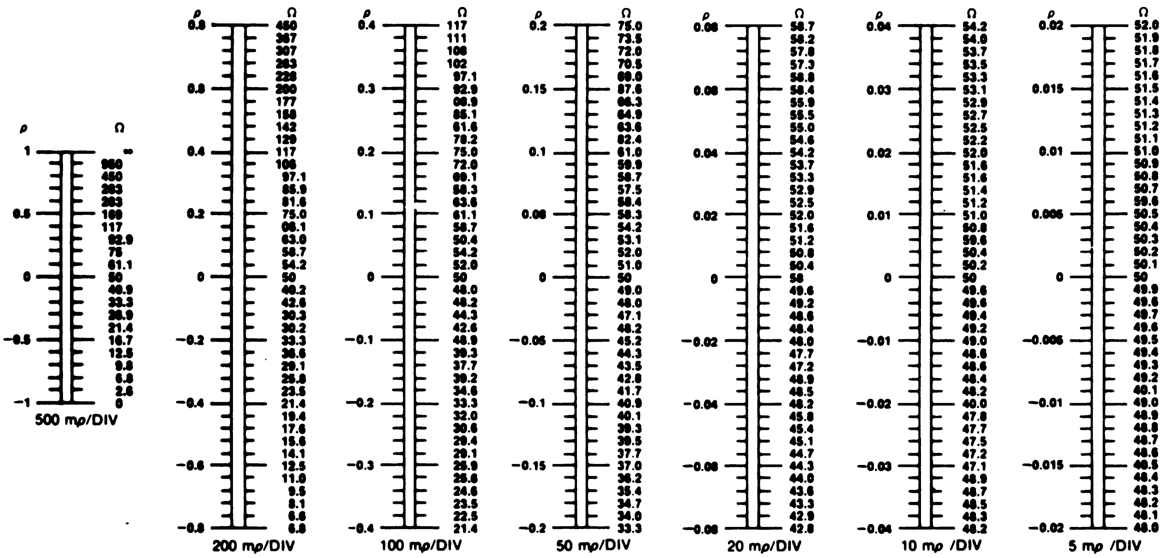
Calibrated distance controls on the equipment allow an operator to examine up to 100 feet of cable with segments as small as one foot displayed horizontally across the ten-division CRT screen. Low-loss cables as long as 2,000 feet may be examined at 100 feet or 200 feet for each



1. CABLE	BNC Connector—delivers pulse to the test cable and receives the reflected return pulse.
2. FOCUS	Adjusts the focus of the crt electron beam.
3. INTENSITY	Controls the brightness of crt display.
4. POSITION/FINE	Vertical position control of the crt display. The outer control is a course adjustment and the inner control is a fine adjustment.
5. m_ρ/DIV	Selects the vertical deflection factor—5 m_ρ/div to 500 m_ρ/div (5-2-1 sequence).
6. POWER	Push-off, pull-on switch—does not affect the battery charging circuit.
7. GAIN	Screwdriver adjust to set the gain of the vertical amplifier.
8. NOISE FILTER	Reduces displayed noise. Display rate is reduced by a factor of 10.
9. BATTERY	Meter to indicate the relative charge of the power pack.
10. ZERO REF CHECK	Momentary contact pushbutton. When pushed, checks the horizontal location of the incident pulse on the crt when the DISTANCE dial is being used.
11. ZERO REF SET	Horizontal pulse position control for crt display. Sets the incident pulse edge to a vertical reference line of the crt when the DISTANCE dial is at 000 or the ZERO REF CHECK button is pushed.
12. MULTIPLIER	Two-position switch (red control) for X.1 or X1 multiplier. Affects both the DISTANCE dial and the FEET/DIV (METRES/DIV) control.
13. DISTANCE	Indicates the distance from the 1502 to the point on the cable where the display window begins. Two ranges: 100 feet (25 m) at X.1 or 1000 feet (250 m) at X1. Disabled when the FEET/DIV (METRES/DIV) is at 200 (FIND) (50).
14. FEET/DIV (METRES/DIV)	Selects the horizontal deflection factor: X1 = 1 – 200 ft/div (25 cm – 50 m/div). X.1 = 0.1 – 20 ft/div (2.5 cm – 5 m/div).
15. CABLE DIELECTRIC SOLID POLY SOLID PTFE OTHER VAR	Three pushbuttons and a screwdriver adjust. Selects the proper velocity of propagation. VAR from 0.55 to 1.0 when the OTHER pushbutton is pressed. Fully CW is for air dielectric. VAR control has reference marks every 30° to indicate relative propagation constants.
16. RECORD	Two position lever switch; pushed up and then released, it initiates X-Y recorder or a chart recorder.
17. AC LINE FUSES	Protection fuses for line power and battery charging circuits (0.5 A fuses for 115 V ac; 0.3 A fuses for 230 V ac).

228.232.1

Figure 6-11.—1502 front panel controls.



DIRECTIONS FOR USE: LOCATE THE COLUMN OVER THE SETTING OF THE mρ/DIV SWITCH. FIND THE ρ VALUE ON THE LEFT SIDE OF THE COLUMN AND READ THE IMPEDANCE ON THE RIGHT SIDE CORRESPONDING TO THE ρ VALUE.

228.233

Figure 6-12.—Impedance nomograph.

division. The horizontal CRT scale is calibrated directly in distance units from 0.1 foot for each division to 200 feet for each division. A three-digit direct reading dial (figure 6-11, item 13) indicates the distance to any cable discontinuity when you use the dial to horizontally position the discontinuity's reflection to a CRT reference line.

For proper operation and measurement concepts of the equipment, refer to the operator's handbook.

FREQUENCY-DOMAIN REFLECTOMETRY (FDR) TEST SETS

Frequency-domain reflectometry (FDR) is a fast, simple, and reliable technique developed to locate defects in microwave cables and waveguide systems connecting receivers, transmitters, and antennas. Like the TDR, the FDR tester permits direct readout of cable distance in feet to the discontinuity (impedance fault). This system has an impressive record of reliability, greatly reduced service time, and improved service standards. Because the FDR checks cables at their actual operating frequencies, discontinuities outside those frequencies will not affect the test. When measurements indicate a fault, its location (in terms of distance in feet from the point of test) can be precisely determined. Repairs, therefore, can be made quickly and efficiently.

FDR VS TDR

Until the advent of FDR testers, cables were primarily tested by means of TDR, a system which has several limitations. For example, TDR makes measurements covering a spectrum determined by its pulse characteristics and therefore detects all discontinuities (including those outside the operating frequency range, which do not affect a system's operation). With FDR, however, the analysis is made at the actual operating frequency band of the microwave system, thereby assuring proper system performance at the operating frequencies.

While FDR works in waveguides and band-limited systems (including transmission networks that contain filters), TDR cannot work in such systems because it requires a transmission line that passes the whole spectrum from the fundamental frequency (2 MHz to 5 MHz) to the highest harmonic (15 GHz). Waveguides which act as high-pass filters cannot transmit TDR pulses. Similarly, TDR cannot see through low-pass or band-pass filters because these eliminate the low-frequency harmonics and appear to display a discontinuity on the TDR's CRT.

FDR TESTING

FDR identifies defective systems by injecting an RF signal into a system and using insertion-loss (attenuation in the line) and return-loss (VSWR) measurements to classify the system under test as good or in need of repair. There are various test setup configurations to measure these losses, based on the particular FDR equipment being used. Figure 6-13 represents a typical test setup for VSWR and insertion-loss monitoring. Such a test configuration provides simultaneous measurement of the losses.

If the input and output connectors of the device under test are accessible, an insertion-loss check verifies input to output performance across the band. For insertion-loss measurement, the network analyzer (figure 6-13) (using its B and REF channels) indicates the ratio of output signal to input signal directly in dB. For tests of long cables whose ends are accessible, the FDR allows measurements from a connector end as far as 2,000 feet from the tester. In some systems to be tested, however, either the input or output connector may be inaccessible. For such systems, a return-loss measurement made on the accessible connector will provide a total system check. For return-loss measurements, the network analyzer (using the A and REF channels) indicates (measures) the ratio of reflected power to incident power (output of the RF sweep oscillator unit) directly in dB. As shown in figure 6-13, the signals in each case are sampled via directional couplers.

Comparison of each measured signal with the incident power of the RF oscillator, supplies automatic compensation for any swept-source power variations across the band, giving a true graph of performance in dB versus frequency on the network analyzer CRT. An example of insertion-loss measurement on the network analyzer CRT is illustrated in figure 6-14. In this example, a loss of less than 10 dB would be

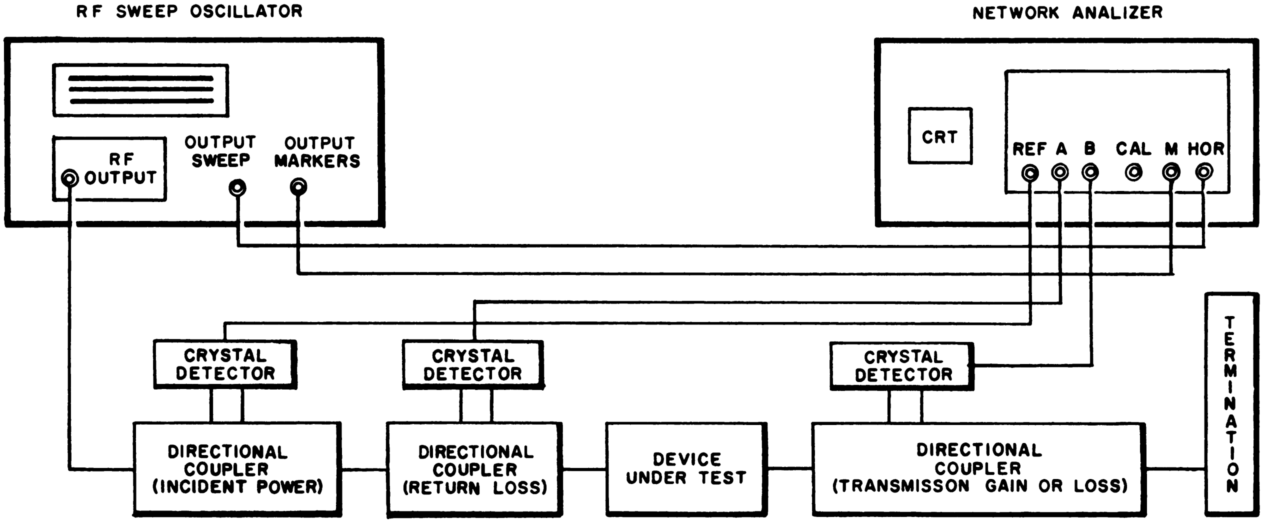


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Figure 6-13.—Typical test setup for VSWR and insertion performance.

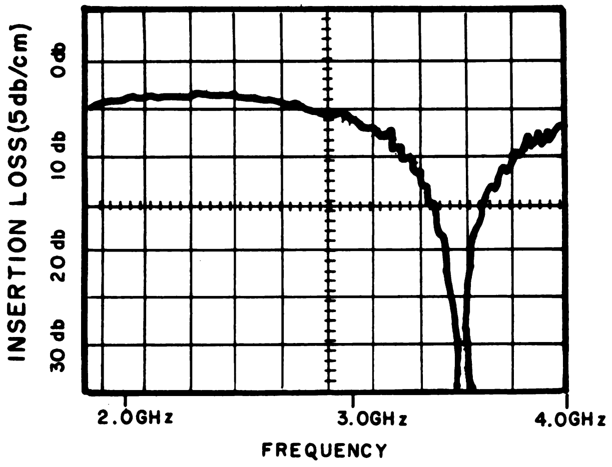

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Figure 6-14.—Insertion-loss display.

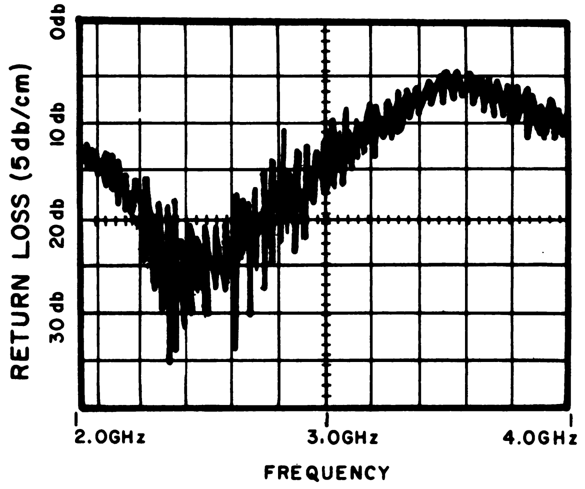

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Figure 6-15.—Return-loss display.

acceptable (as determined from previous tests of a good system.) The cable, however, needs repair because a fault (discontinuity) is present, which produces an insertion-loss greater than 35 dB at a frequency of 3.56 GHz.

An example of a return-loss measurement for the same cable is shown in figure 6-15. Here a loss of 11 dB (as previously determined from a good system), which corresponds to a VSWR of 1.8, would be acceptable. At 3.56 GHz however, the return loss on the CRT indicates 5 dB, which corresponds to a VSWR of 3.6, and is unacceptable.

The dual-channel network analyzer in figure 6-13 permits the display of both measurements simultaneously, and both verify the discontinuity in the system cable under test. Single-channel FDR testers require individual test setups for measuring insertion and return losses, and comparison of the individual graphs.

Determining Cable Lengths or Distance to Faults

To determine cable length or fault (discontinuity) location measurements, a waveguide or coaxial "tee" is incorporated in the test setup. (See figure 6-16.) The FDR test setup is then calibrated with a calibration cable (provided with FDR set) to establish a known 0 feet reference on the CRT display. Then the system cable to be tested is connected to the tee. The resultant CRT display of the network analyzer consists of a stationary pattern containing a series of "half-dome ripples." A count of the total number of these ripples indicates the number of feet from the cable end to the fault, as is illustrated in figure 6-17. The FDR display is from the cable, which needs repairs, shown in figures 6-14 and 6-15. By multiplying the 5-2/3 ripples displayed, by the calibration factor of 2 feet per ripple (CRT calibrated that way) you can identify the location of the fault (11-1/3 feet from the cable end connector). Figure 6-18 illustrates a dual-channel display of the cable after the repairs were completed. The insertion-loss is less than 10 dB and the return-loss is greater than 11 dB, indicating proper performance of the system cable.

Detailed FDR Analysis

With the sweep oscillator output, the transmission system under test, and the crystal detector all connected to the same tee junction, discontinuities and/or termination mismatch in the system reflect some of the incident power. The reflected power combines with the incident

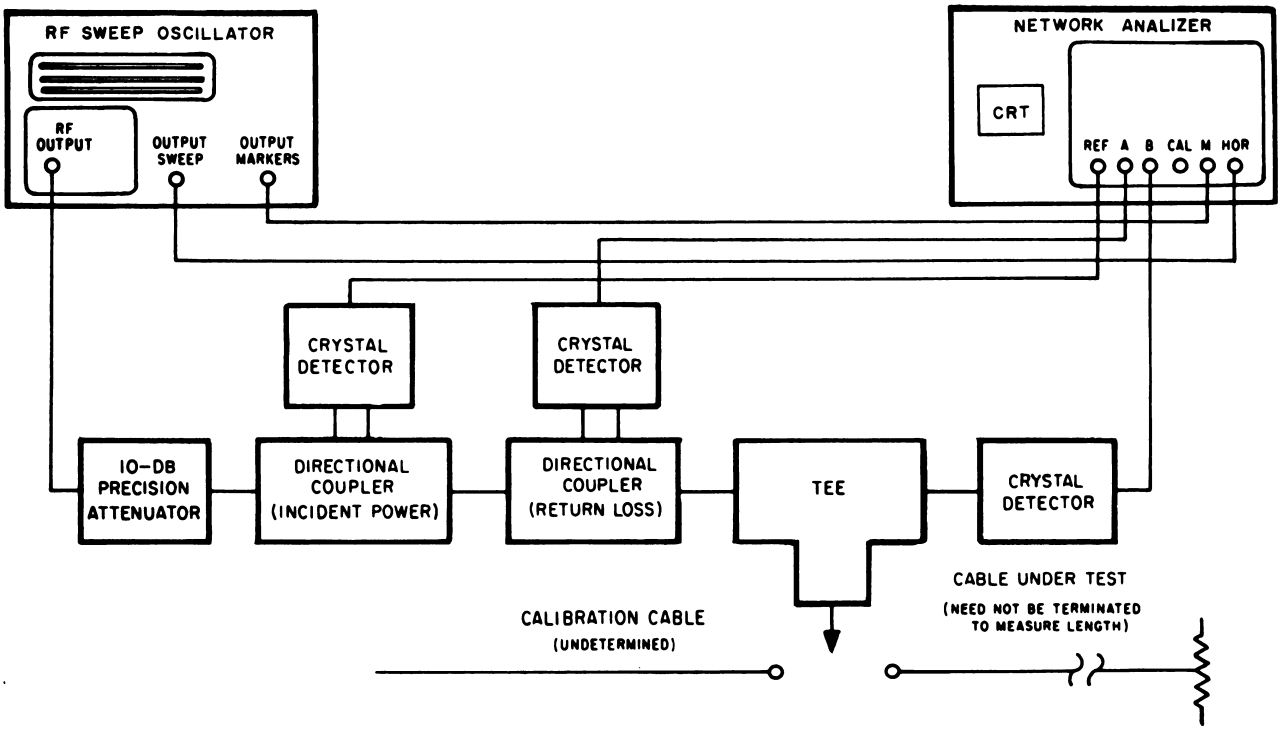

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Figure 6-16.—Test setup for fault-location measurement.

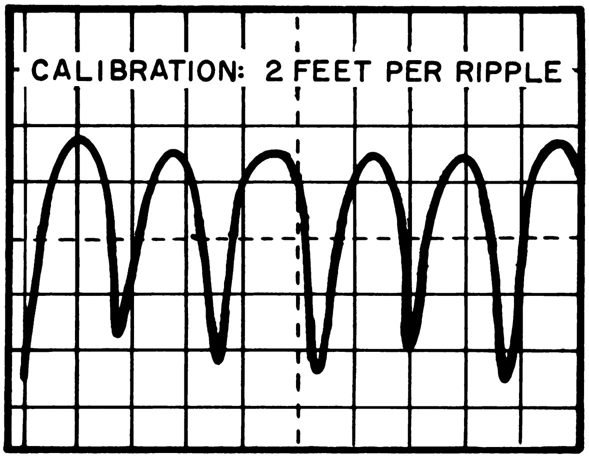

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Figure 6-17.—Measuring a cable fault.

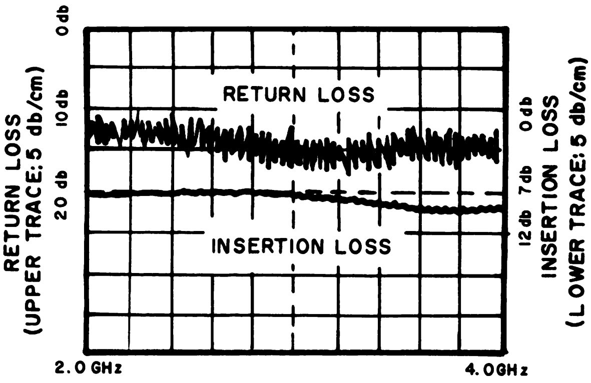

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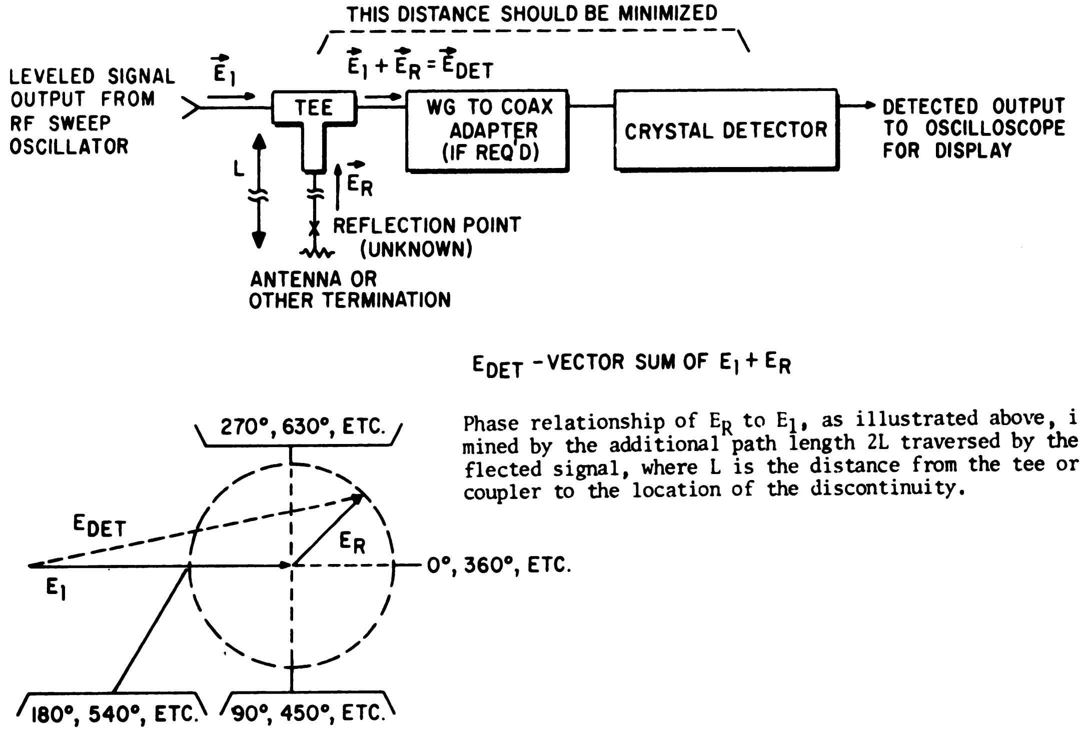
Figure 6-18.—Dual-channel display of a repaired cable.

signal at the crystal detector, resulting in a changing phase relationship that depends upon both distance to the discontinuity and signal frequency. As the frequency is swept, it changes the number of wavelengths which occupy the fixed


THIS DISTANCE SHOULD BE MINIMIZED
LEVELED SIGNAL OUTPUT FROM RF SWEEP OSCILLATOR
$\vec{E}_I$
$\vec{E}_I + \vec{E}_R = \vec{E}_{DET}$
TEE
WG TO COAX ADAPTER (IF REQ'D)
CRYSTAL DETECTOR
DETECTED OUTPUT TO OSCILLOSCOPE FOR DISPLAY
L
$\vec{E}_R$
REFLECTION POINT (UNKNOWN)
ANTENNA OR OTHER TERMINATION
E_{DET} - VECTOR SUM OF $E_I + E_R$
270°, 630°, ETC.
E_{DET}
E_R
0°, 360°, ETC.
E_I
180°, 540°, ETC.
90°, 450°, ETC.

Phase relationship of E_R to E_I, as illustrated above, is determined by the additional path length 2L traversed by the reflected signal, where L is the distance from the tee or hybrid coupler to the location of the discontinuity.

228.235

Figure 6-19.—Magnitude of the vector sum.

path from the tee to the point of reflection and back. The display thus will show amplitude "ripples" which result from the summing of the incident and reflected signals. This relationship changes with frequency. Figure 6-19 illustrates how the magnitude of the vector sum of these signals, which is the signal level detected for display, varies with frequency.

The resultant display of the varying-magnitude detected signal is actually a logarithmic swr presentation. The ripple peaks are adjacent VSWR maxima which occur, during the sweep, at each frequency in which the "round-trip" length of the reflected wave path from the source to the defect has changed by one wavelength. The number of ripples appearing across the full width of the display (which is inversely proportional to the frequency separation of adjacent ripples) is a measure of the distance from the discontinuity to the crystal detector. Therefore, direct readout of fault distance is provided when the swept source is operated over a sweep width (ΔF), which is chosen to provide a display calibration (in terms of ripples per foot) compatible with the length of the transmission system under test.

In a coaxial system, it can be shown that the distance to a discontinuity, which may be a fault or the cable end, is represented by the equation:

$$D = \frac{492\ K\ N}{\Delta F}$$

Where D is the distance to the fault or cable end in feet; 492 is the half wavelength in feet of a 1-MHz wave in free space transmission; K is the propagation constant which relates the propagation velocity in the coaxial system to the velocity in free space; N is the number of ripples observed in the display; and ΔF is the swept-frequency excursion (sweep width) of the signal source in MHz. Note that for any type of cable, ΔF can be selected to equal 492K, so that the distance in feet is equal to the number of ripples (including the fractional ripples) shown in the display. In waveguide systems, the distance down the waveguide to the fault is represented by the same equation, with K denoting the relation $\frac{\lambda}{g}$ (λ is the wavelength in free space and g is the wavelength in the waveguide) at the frequency of measurement.

SWEPT FREQUENCY TEST SET AN/USM-402(V)

The AN/USM-402(V) is a portable FDR testing device developed to support the testing of RF transmission lines and devices installed in naval aircraft. It can be used at shore station facilities or aboard aircraft carriers. It can be used to measure and record insertion loss and return loss of units under test and to locate faults (discontinuities) in transmission lines. The tester (see figure 6-20) consists of a three-wheeled cart, a recorder used for recording cartesian coordinate graphs of voltage versus time (see figure 6-21 and table 6-1), a frequency response test set (similar to the network analyzer previously discussed), and a radio-frequency oscillator

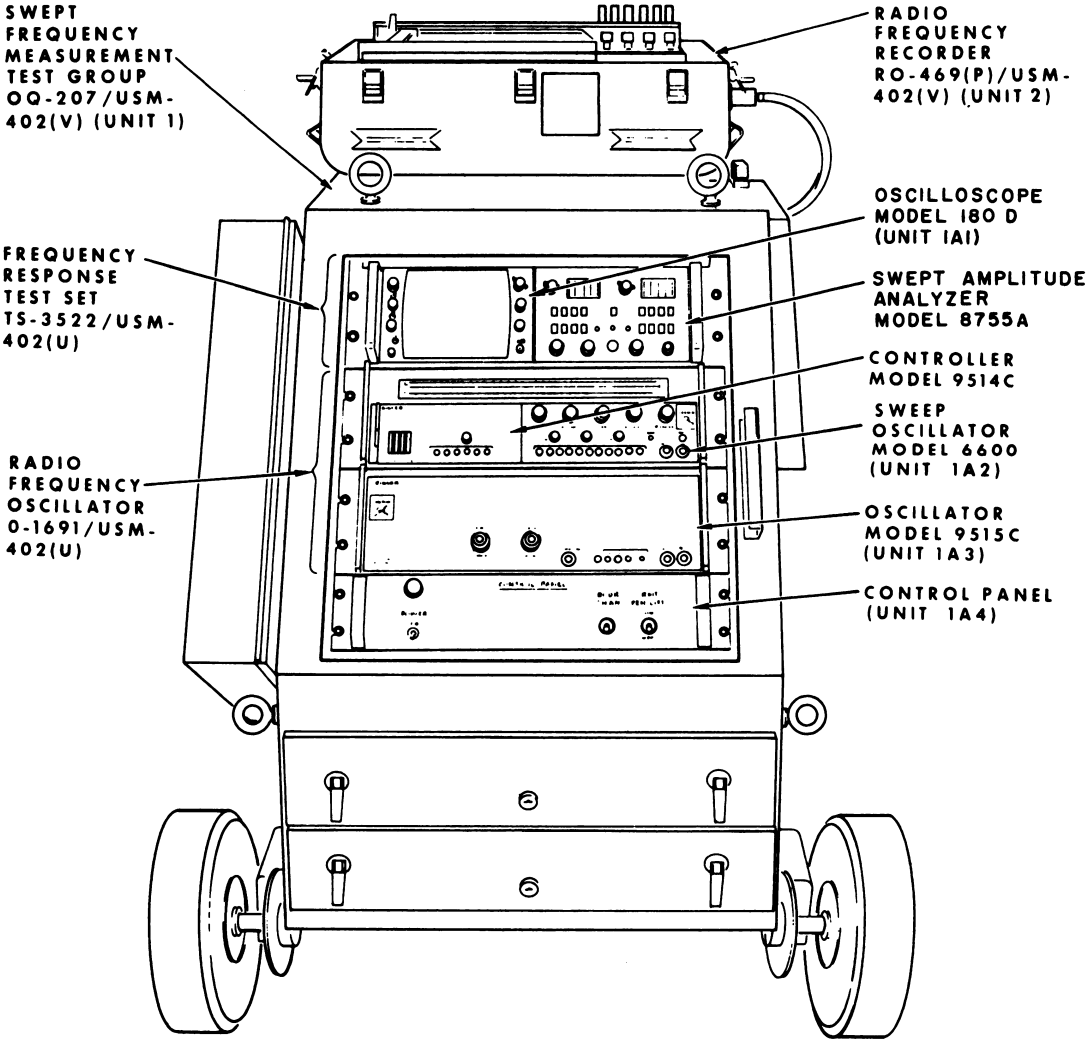

SWEPT FREQUENCY MEASUREMENT TEST GROUP OQ-207/USM-402(V) (UNIT 1)
RADIO FREQUENCY RECORDER RO-469(P)/USM-402(V) (UNIT 2)
OSCILLOSCOPE MODEL 180 D (UNIT 1A1)
FREQUENCY RESPONSE TEST SET TS-3522/USM-402(U)
SWEPT AMPLITUDE ANALYZER MODEL 8755A
CONTROLLER MODEL 9514C
SWEEP OSCILLATOR MODEL 6600 (UNIT 1A2)
RADIO FREQUENCY OSCILLATOR O-1691/USM-402(U)
OSCILLATOR MODEL 9515C (UNIT 1A3)
CONTROL PANEL (UNIT 1A4)

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Figure 6-20.—Swept Frequency Measurement Test Set AN/USM-402(V).

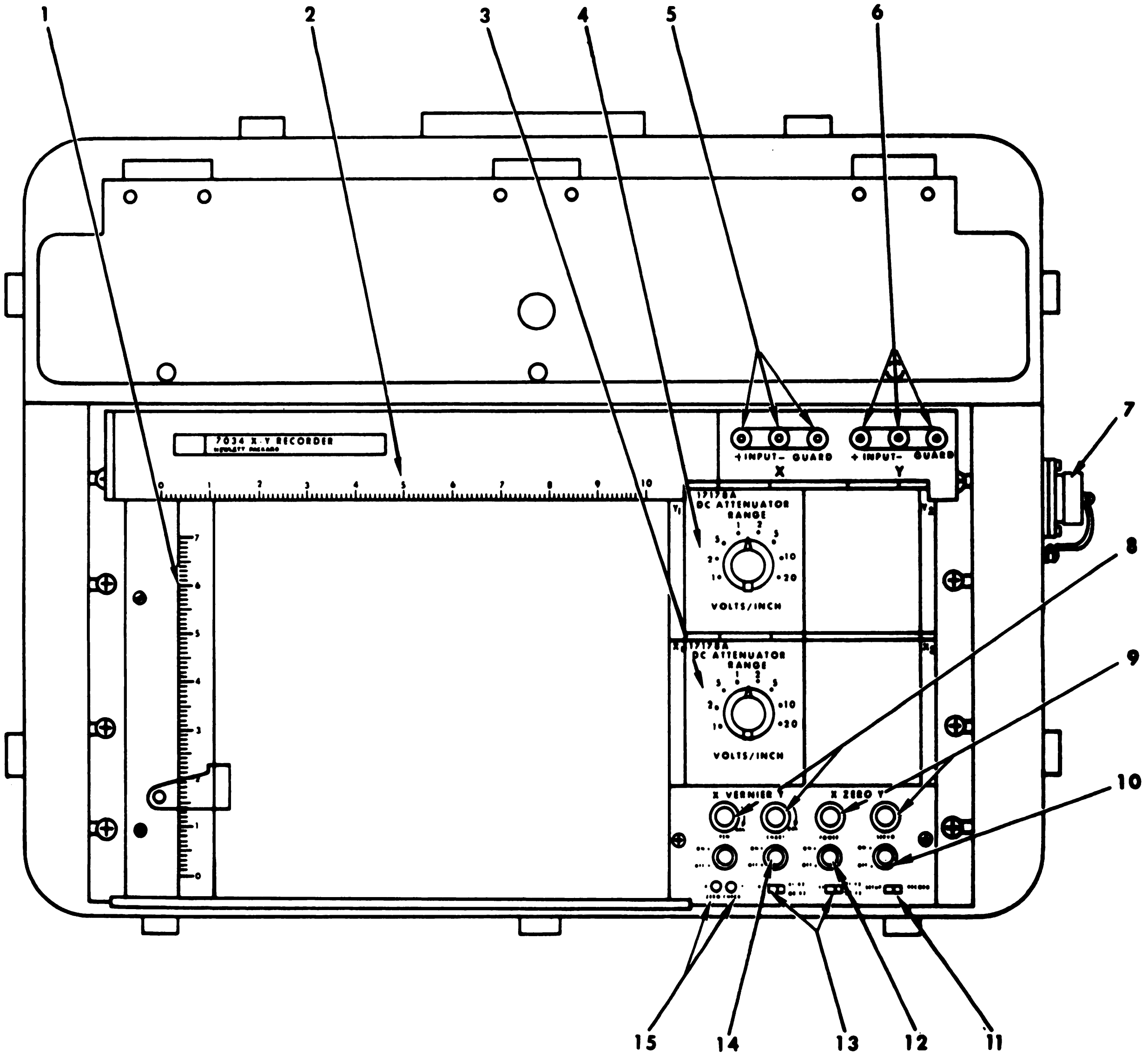

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Figure 6-21.—Radio Frequency Recorder RO-469(P)/USM-402(V) controls and indicators.

(similar to the RF sweep oscillator previously discussed.)

The unit operates on either 115 V ac or 230 V ac, 48 to 400 Hz, and has an operating frequency range of 10 MHz to 18 GHz. The output of the RF oscillator can be swept or tuned to a single frequency within the band. The operation of this equipment is similar to the typical tester previously discussed. For operating procedures, equipment characteristics, etc., refer to NA17-15LAA-37.1. It is beyond the scope of this manual to teach the operation of specific test sets; however, the general explanation given here should assist you in interpreting the information you will see concerning specific equipment.

Table 6-1.—Radio Frequency Recorder RO-469(P)/USM-402(V) Controls and Indicators

Index No.	Controls and Indicators	Purpose
1	Y Axis Scale	A moveable scale (calibrated in inches) used to determine pen Y position
2	X Axis Scale	A stationary scale (calibrated in inches) used to determine pen X position
3	X_1 Axis DC Attentuator (Unit 2A3)	Model 17178A is a dc attenuator which provides eight ranges from 0.1 V/in to 20 V/in for the X axis
4	Y_1 Axis DC Attenuator (Unit 2A2)	Same as index No. 3 except applies to Y axis
5	X Input Terminals: +INPUT (J101) −INPUT (J102) GUARD (J103)	Three input terminals for the X axis that are connected in parallel to an auxiliary jack (J902) on the rear of the unit. Each terminal is capable of accepting either open wire or banana plug connectors
6	Y Input Terminals: +INPUT (J201) −INPUT (J202) GUARD (J203)	Same as index No. 5 except applies to Y axis
7	Connector 2J1	Unit 2 input connector which normally mates with W3P1. Mates with W4P1 when the recorder is used separately
8	X VERNIER Control (R102) Y VERNIER Control (R202)	A vernier control in each axis for multiplication of input range. Settings from X1 to X2.5. Extreme clockwise position is a calibrated condition (switch actuated). A lock is provided to prevent accidental alteration of setting of each control
9	X ZERO Control (R110) Y ZERO Control (R210)	A control in each axis for controlling pen zero position on the chart. A lock is provided to prevent accidental alteration of this setting
10	SERVO Switch (S601)	A pushbutton switch that controls servo actuation for both axes. When the servos are energized, the switch indicator lamp lights
11	SETUP/RECORD Switch (S602)	SETUP position for making pre-recording adjustments. RECORD position for all other recordings
12	POWER Switch (S901)	A pushbutton that controls application of the AC line voltage to the recorder. When the AC line voltage is applied to the recorder, the switch indicator lamp lights
13	Module Selector Switch: $X_1/X_1 \cdot X_2$ or X_2 (S102) $Y_1/Y_1 \cdot Y_2$ or Y_2 (S202)	The module selector switch in each axis can connect two plug-ins to the main frame. For this model, the switches should remain in the X_1 and Y_1 positions. (Modules must be in X_1 and Y_1 positions to couple signals to the main frame)
14	CHART Switch (S1001)	A pushbutton switch that controls the application of power to the autogrip. When the autogrip is energized, the switch indicator lamp lights
15	X ZERO CHECK Switch (S101) Y ZERO CHECK Switch (S102)	A momentary pushbutton switch in each axis for verifying zero setting of the axis. When the switch is pressed, any input signal to the main frame input is interrupted and the recording pen returns to its quiescent position

CHAPTER 7

MAGNETIC RECORDERS

Magnetic recorders are used throughout the Navy in various forms and types. Whether it be the simplest audio recorder or the most complex data recorder, all provide a handy, compact means of storing and retrieving large amounts of information. This makes magnetic recording useful in handling the Navy's ever expanding technology and the libraries of information and data needed to support this technology. Some examples of the information- or data-recording uses are audio for voice and music, ECM signals, sonobuoy signals, video, and computer data. We also use equipment that does not have the ability to record, for example: magnetic ink readers, magnetic card readers, audio-visual projectors with magnetic sound, "play only" audio decks, and "read only" decks for the control programs of computers and automated test equipment. All the different types of equipment operate on the same principle; rearrangement of the particles of a magnetic medium and detection of that rearrangement. (See figure 7-1.) In the following chapter, we will explain the theory of recording and reproducing techniques and will follow with the basic forms of major types of equipment. The electronic circuits needed for the explanations are in functional block form, since actual circuits are beyond the scope of this chapter and are covered in depth in the maintenance instruction manuals for the respective pieces of equipment.

OPERATION OF A MAGNETIC RECORDER

Operation of a magnetic recorder involves three basic processes: recording, reproducing, and erasing. In analog systems, reproducing is called "playback" or "play." In digital systems, record is "write," and reproducing is "readback" or "read."

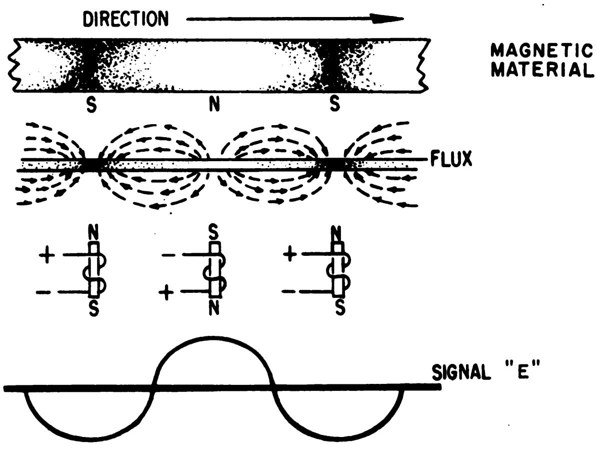

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Figure 7-1.—Magnetization principle.

RECORDING OR WRITING

If a material capable of being magnetized is placed near a magnetic field, the molecules of the material will become oriented according to the direction of the magnetic field. This magnetic field is usually electronically controlled, and it is produced by current flowing through a coil of wire. Most magnetic media consist of finely divided iron-oxide particles or other permeable material deposited upon a backing. When the medium is moved through a magnetic field, the particles are aligned according to the instantaneous direction and magnitude of the magnetic field, as illustrated in figure 7-1. Note the formation of the signal "E" (shown in the figure) when the medium moves from left to right.

The magnetic field is produced in the gap of a recording head over which the recording medium passes. The recording head is a split-ring electromagnet. (See figure 7-2.) It consists of an incomplete ring of highly permeable material inserted into a coil of wire. The signal to be recorded is applied to the coil, causing current to flow through the coil. The varying current creates a varying magnetic field in the gap, and a fringing flux field which penetrates the recording medium. The fringing flux field has a trailing action down the recording medium following the head. This causes distortion of the recorded signal by slightly rerecording over the desired signal. (This distortion problem will be discussed in more detail later in analog and digital recording.)

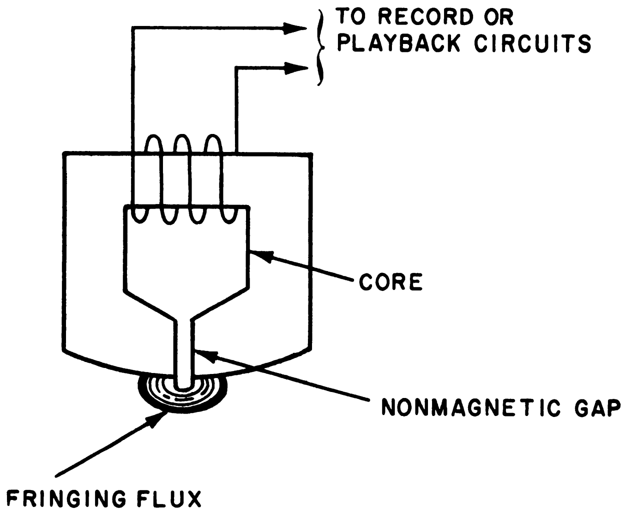

Figure 7-2.—A split-ring electromagnet.

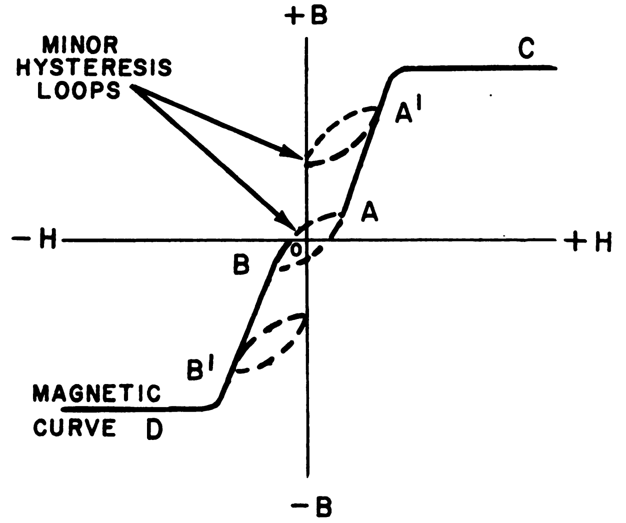

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Figure 7-3.—Magnetization curve of a typical magnetic reading medium;

A graph of the magnetization curve of a typical recording medium is shown in figure 7-3. The magnetizing force, H, produced by and proportional to the record head winding current, is plotted along the abscissa, and the resulting flux density, B, is along the ordinate. Points C and D are saturation or maximum flux density and vary with the permeability of the recording medium used. If positive and negative currents are alternately applied, then H moves from 0 to +H and −H. Likewise, B goes from 0 to +B and −B. (Recalling the right-hand rule will help in understanding this action.) Note that near the point of origin, 0, the curve from A to B is extremely nonlinear due to hysteresis. Also note that there are hysteresis loops at points A′ and B′. The effects of these hysteresis loops result in a typical recording curve as shown in figure 7-4. In digital recording, the recording medium is driven to saturation region, points C and D, and the nonlinear portion has negligible effect. In analog recording, saturation is avoided, and the nonlinear portion is of concern.

Keep in mind that "analog" recording and "digital" recording refer to recording techniques and not to the information being recorded. In the following paragraphs, analog processes will be explained; in the last part of the chapter, the digital process will be given and compared with analog.

Analog Recording

Analog recording techniques are used mainly for recording audio signals that are normally listened to by ear. In addition, information that

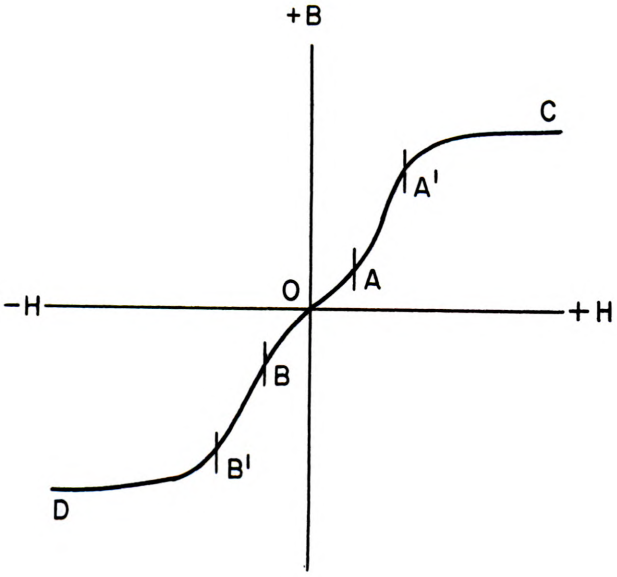


Figure 7-4.—Recording curve of a typical magentic recording.

has been processed to produce a signal suitable for analog recording is used as follows:

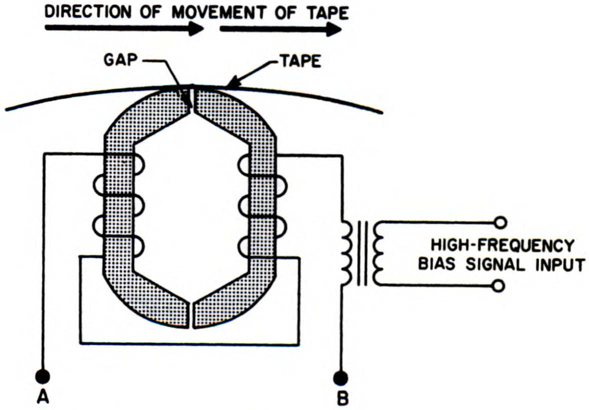
- To record digital information, which is recorded as different tones to represent data.

- FSK (frequency shift keying), in which the signals are typically 4 to 8 cycles.

- FM (frequency modulation), in which a tone is recorded, and the deviation from a set frequency is the information. (Very large bandwidths are easily accomplished by "scaling," or compressing before recording and expanding after playback. FM is used for video signals and for varying analog voltages, such as those from a transducer.)

In analog recording, magnetic tape is the most commonly used recording medium. It consists of finely divided iron-oxide particles or other permeable material deposited upon a plastic backing. When the tape is moved through a magnetic field, the particles are aligned according to the instantaneous direction and magnitude of the magnetic field which is produced in the gap of the recording head over which the tape passes. As previously noted, near the point of origin, 0, the curve is extremely nonlinear due to hysteresis. Consequently, the amplitude of the signal recorded on the tape would not be directly proportional to the amplitude of the signal applied to the recording head. This distortion is greatly reduced by the application of a high-frequency (typically from 50 kHz to 100 kHz) constant-amplitude bias signal which is mixed with the signal being recorded. This is usually accomplished in the last stages of the recording amplifier or by mixing the bias oscillator with the analog signal in a transformer as shown in figure 7-5.

While the tape is in the recording gap (see figure 7-5), the bias causes the magnetic characteristics of the iron oxide to follow the dashed lines of the minor hysteresis loops. (See figure 7-6.) As the tape leaves the gap, the influence of the magnetic field created by the bias is reduced to zero, and the tape assumes a permanent magnetic pattern which is proportional in magnitude and direction to the signal of the gap flux field. Nonlinearities are also in the frequency response of the head and tape. These are dealt with in the recording amplifiers by compensation networks. As previously mentioned, the fringing flux also has an effect, and this is most detrimental to the higher frequencies. Narrowing the head gap


DIRECTION OF MOVEMENT OF TAPE
GAP
TAPE
HIGH-FREQUENCY BIAS SIGNAL INPUT
A
B

THE SIGNAL TO BE RECORDED IS APPLIED ACROSS INPUTS A AND B.

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Figure 7-5.—Recording head principle.

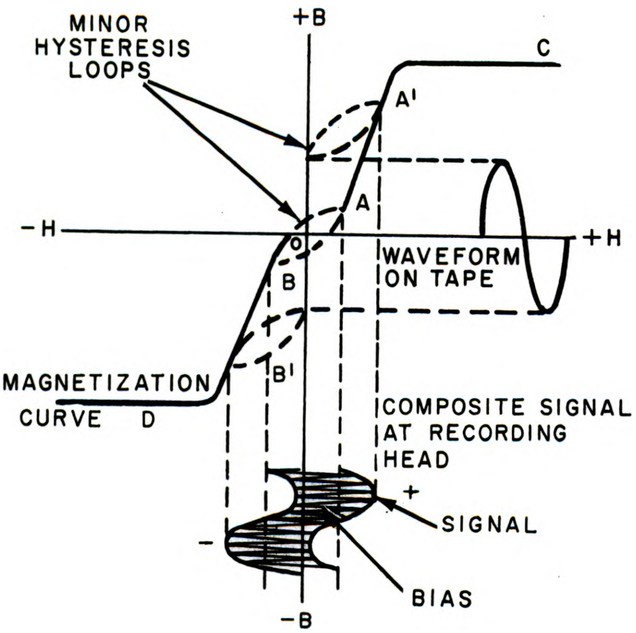

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Figure 7-6.—Recording with bias.

narrows the width of the flux gap and increases the usable frequency range. Typical record head gaps range from 6 to 15 microns; however, some combination record/playback heads use a gap as small as 1.5 microns. (A micron is .000001 of a meter.) Increasing the speed of the tape motion across the head has the same effect as narrowing the head gap. The relationship is, however, not simple. For instance, doubling the speed does not double the frequency response.

Another approach used to narrow the fringing flux field is a technique called "cross-field recording." Two forms of cross-field recording are used; the simplest is a narrow highly permeable bar aligned directly opposite and parallel to the record head gap on the back side of the tape. (See figure 7-7.) The polarity signs are for a positive current and they would reverse for a negative current. The second form, illustrated in figure 7-8, shows the cross-field approach using a bias only record head which is connected so that the magnetic fields operate in a push-pull mode. In both cases, the cross-field devices run in contact with the back of the tape and the tape is sandwiched between them and the record head.

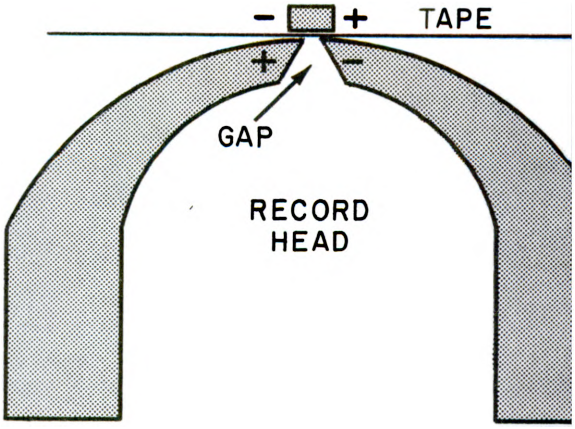

Figure 7-7.—Cross-field with bar.

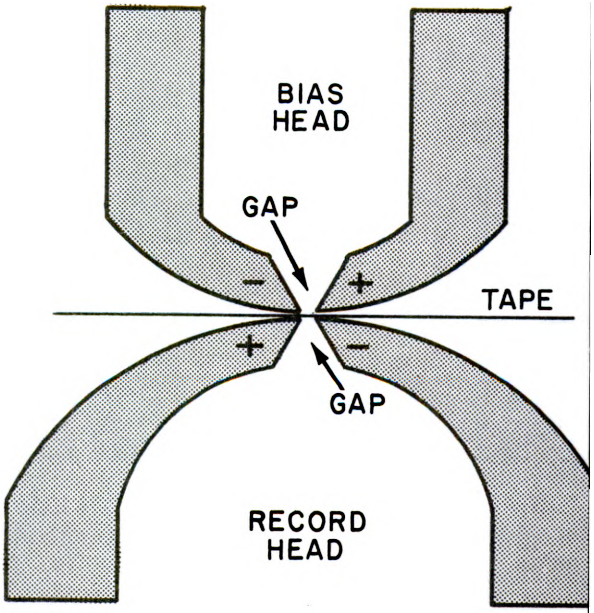

Figure 7-8.—Cross-field with bias head.

REPRODUCTION OR PLAYBACK

After the recording process, there exists on the tape a flux pattern which is proportional in magnitude and direction to the signal recorded on it. If the tape is then moved past the gap of a reproducer or playback head (similar in construction to the record head), the magnetic flux of the moving tape will induce a voltage in the coil of the reproducer head. The data is thus detected.

In a tape recorder, playback is the process of detecting the magnetic modulation (intelligence), amplifying this intelligence, and feeding it to a loudspeaker or other output unit. As the many individual magnetic fields which have been impressed on the tape pass by the pickup head, they induce a voltage into the pickup coil. (See figure 7-9.) This voltage, when properly amplified, reproduces the data recorded on the tape.

The Playback Head

The gap in the reproducer (playback) head should be as small as practical so the gap will intercept less than one wavelength of the signal on the tape at the highest frequency to be reproduced. However, as the gap is made smaller, the induced voltage decreases. This means there is a practical limit to decreasing the gap and still maintaining an adequate signal-to-noise ratio. Tape playback heads vary in design according to the application, but typical head gaps of .5 to 3 microns are common.

The voltage across the coil increases directly as the tape's speed and the frequency increase. If the speed and the gap width are assumed to be constant, the output voltage from the head is directly proportional to the frequency, as long as the wavelength on the tape is large compared to the gap width. This results in an output-versus-frequency characteristic curve in which the output steadily increases as the frequency increases. However, the voltage does not continue to rise indefinitely with the frequency. As electrical losses in the core material increase, and as the wavelength on the tape approaches the same dimensions as the reproducer head gap, the actual output will reach its peak and then begin to decrease as the frequency continues to increase.

The Playback Amplifier

A playback amplifier (high-gain preamplifier) is used to amplify the small voltages picked up by the playback head. The amplified signal is then coupled into a stage of amplification called an equalizer. This stage compensates for the greater amplitude of the middle and low frequencies and the loss of amplitude of the other frequencies. Thus, this stage provides an additional boost or reduction of high frequencies, depending upon the nature of the program material and the preference of the operator. After equalization, the audio signal is usually further amplified and fed to a loudspeaker. (It should be noted that a separate amplifier must be provided to record and play back each channel (track) of intelligence.)

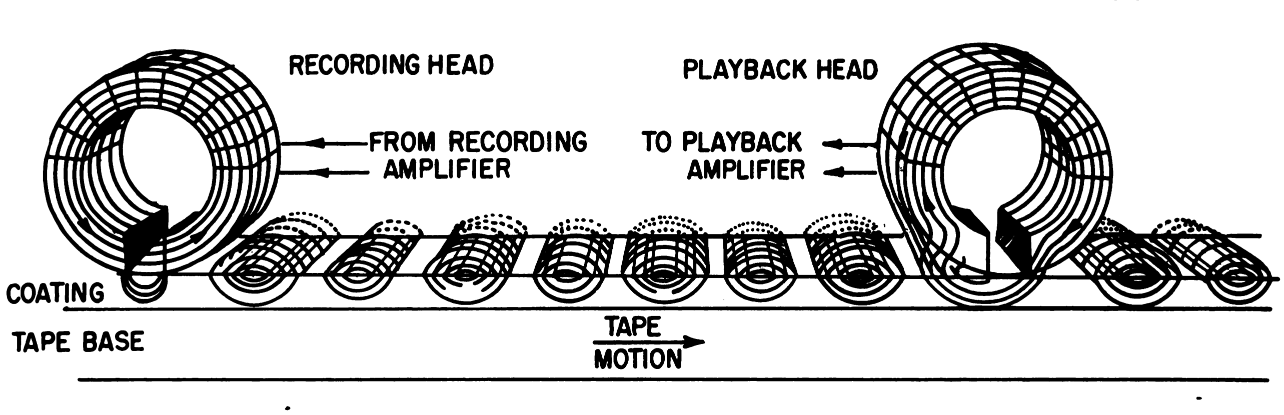

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Figure 7-9.—Magnetic flux lines.

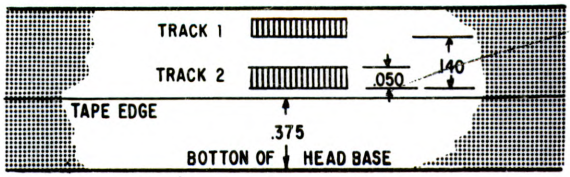
Fidelity

One of the several factors on which the fidelity of the reproduction is dependent is the speed at which the tape is passed over the record head. When sound pulses are recorded at a low tape speed, the resulting magnetic fields are very close together. When the tape speed is increased, the magnetic fields are extended along the tape (making fidelity reproduction easier), and the distances between the individual magnetic fields are also increased. This permits more separation of the individual pulses, thus increasing the fidelity of reproduction. (Standard tape speeds are given in inches per second (ips); 1 2/8 ips, 3 3/4 ips, 7 1/2 ips, 15 ips, 30 ips, are common tape speeds, though there are some special purpose recorders which operate at speeds up to 150 ips.) Other factors which affect the quality of a recording and its reproduction are materials used in coating the tape, correct storage and handling of the tape, recording techniques, and quality of electronic and mechanical components.

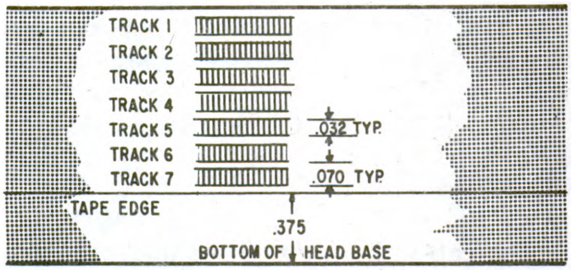
ERASING

The term "erasing" refers to an electromagnetic process, or demagnetizing procedure, which removes signals previously recorded without affecting the magnetic tape in any other way. The action is a realignment (or polarizing) of the oxide particles on the tape so that all modulation (recorded data) is removed, making it possible to reuse the same tape.

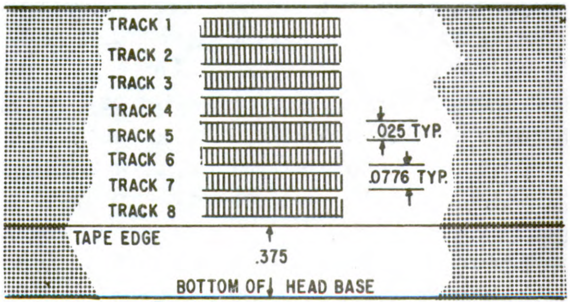
An erasing head which is similar in general construction and appearance to the record head is used to realign the particles. The erase head has a gap width twice that of the record head. This produces a very large magnetic field to ensure that the tape's full width is demagnetized. By placing a relatively high voltage at the erase head, an external field is produced at the point of tape contact that is sufficient to ensure complete erasure. With an ultrasonic erase frequency of 50,000 Hz, and a tape speed of 7 1/2 ips, each magnetic particle is subjected to over 150 reversing magnetic fields as it travels the width of the gap. This number of reversals is more than adequate to cause complete erasure.



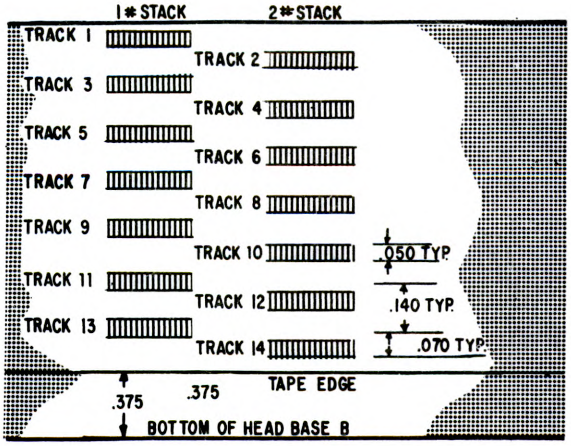
2-TRACK, $\frac{1}{4}$ INCH TAPE, IN-LINE HEAD



7-TRACK, $\frac{1}{2}$ INCH TAPE, IN-LINE HEAD



8-TRACK, $\frac{5}{8}$ INCH TAPE, IN-LINE HEAD



14-TRACK, 1 INCH TAPE, STAGGERED HEAD

243.359

Figure 7-10.—Track arrangements.

HEAD AND TRACK ARRANGEMENTS

Typical track arrangements are illustrated in figure 7-10. There is an almost unlimited variety of arrangements, depending upon the manufacturer, application, and so forth. The tape and the record and playback heads vary in design accordingly. The head assembly consists of a head mounting plate and a number of heads stacked together. The exact number of stacked heads depends on the tape width, track arrangement, and type of head. The heads are mounted on a precision plate assembly (located on the tape transport mechanism) in a way that allows the head stacks to be aligned precisely with the tape.

There are several standard arrangements of heads in head stacks, one of which is shown in figure 7-11. In-line heads (7-, 8-, 14-, and 16-track arrangements) are normally used in computer applications where track-to-track crosstalk is not an important consideration. Staggered or interleaved track arrangements are normally used in data recording and reproducing applications where crosstalk must be kept at a minimum. Tapes recorded on one type of head stack arrangement cannot be reproduced on another type. For example, if sound is recorded on a 7-head, in-line arrangement, the sound must be reproduced from the tape on a 7-head, in-line arrangement.

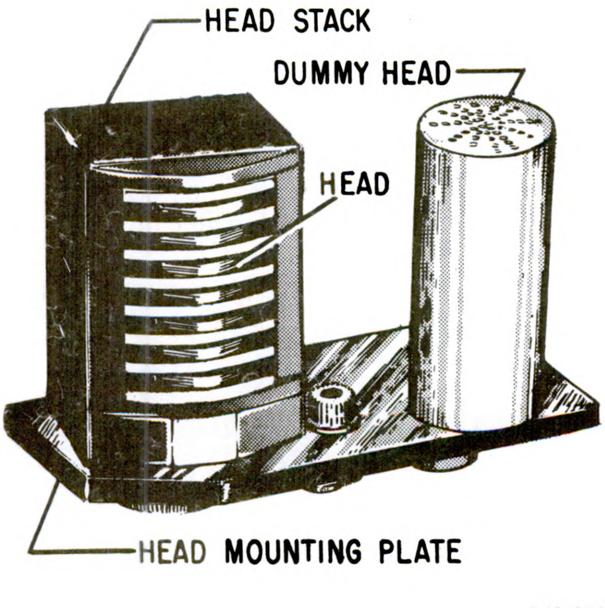


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Figure 7-11.—Multiple-head assembly.

HEAD CARE

Proper care of the magnetic heads involves both cleaning and demagnetizing. Cleaning should be done whenever there is an appreciable build up on the heads or once for every eight hours of operation. Remember that magnetic loss is by the square of the distance, so a little dirt goes a long way when it holds the tape away from the head.

CLEANING MAGNETIC HEADS

Oxide particles from magnetic tapes, ambient dust and salts, (and in some geographic localities, volcanic pumice or ash) will accumulate on the heads. This accumulation reduces efficiency and, if not periodically removed, can lead to a drastic reduction in head life due to the abrasive cutting action on the face of the head. One indication of head wear is the loss of high-frequency response as the gap is cut down to a wider opening.

Magnetic heads are normally cleaned with a cotton swab or a soft lint-free cloth that has been soaked in an approved cleaner. You should refer to the maintenance instruction manual for the unit you are maintaining before you use any head cleaner. This will ensure that you know the proper materials to use and the proper procedures to follow.

DEMAGNETIZING HEADS

Through repeated use, heads often become slightly polarized (magnetized in one direction). This causes "noisy" tapes, especially at higher frequencies. A demagnetizing process called "degaussing" is used to eliminate the residual magnetization (polarization) and restore neutrality to the head. Degaussing is usually not needed as often as cleaning. However, when demagnetizing is needed, ALWAYS clean first. Restoring the neutral condition to magnetic heads cannot be done reliably unless they are clean. To demagnetize the heads, a special degausser is used as described below.

(NOTE: Be sure you do NOT allow the degausser (head demagnetizer) to touch the head. The minimum recommended distance is 1/16 inch.)

1. Plug the degausser in, holding it 4 to 6 feet from the head assembly.
2. Move the degausser toward the head assembly, SLOWLY, avoiding any sudden movements.
3. Once you have positioned the degausser in close proximity to the head assembly, make four to six passes over the entire surface.
4. SLOWLY remove the degausser from the head assembly with a circular motion to a distance of 4 to 6 feet, then unplug the degausser.

TAPE TRANSPORTS

The function of the mechanical section of a magnetic tape recorder is to transport or move the tape during the recording, rewind, and playback operations. This procedure requires coordinating the means for holding a reel of tape, feeding or unreeling the tape at a controlled speed past the record head, and then rewinding it after the recording process has been completed. High-speed shuttling of the tape from one reel to the other is required of the mechanical system. The tape must move quickly and stop quickly in order for a specific section to be located. These abrupt starts and stops must not break or strain the tape. In addition, the braking system must avoid tape spillage when rapidly rotating reels are stopped.

Generally, the electrically driven systems employ carefully balanced motors, seamless belts, extremely accurate pulleys, tension-setting devices, balanced rubber-rimmed wheels, and servos. The arrangement, complexity, and number of components invariably reflect the designer's compromise with the factors of cost, performance, size, and weight.

DIGITAL RECORDING

The fundamental difference between analog and digital recording is in the method and degree of magnetizing of the recording media. For analog recording, linearity and low distortion are the primary requirements. Looking at the B versus H curve, figure 7-4, the linear portions are A to A′ and B to B′. The high-frequency bias ensures operation in the linear regions from A′ to B′. However, for digital recording (as in most digital systems) there are only two states; 0 or 1, ON or OFF, TRUE or FALSE, or whatever names are convenient. Referring to figure 7-4 on the B versus H curve, points C and D provide the two needed states for digital recording. Each of these points is in the saturation regions where a further variation of magnetizing force results in a negligible variation of magnetic intensity in the recording media, and both points are in regions at opposite polarity. Each excursion from one saturation polarity to the opposite is of significance in digital recording. These magnetic polarity reversals are called flux transitions or flux reversals and, generally, less than one to a maximum of two are required per bit of digital information. In analog recording, the information is in a faithful reproduction of the continuously varying analog current. In digital systems, the data or information is in the flux transitions. There are many different combinations in which the transition can be used to designate a 1 or 0. (Polarity, position, or relative spacing of the transitions are all possibilities.) The process of assigning information to the flux transitions and recovering it is termed "encoding" and "decoding."

There are advantages to operating in the saturation regions of the magnetic medium. During read back, the signal in the magnetic data transfer head is proportional to the rate of change of the flux. This is expressed by the following formula:

$$e_R = \frac{d\Phi}{dt}$$

where e_R = instantaneous read head voltage

N = number of windings around head core

$\frac{d\Phi}{dt}$ = change of magnetic flux per unit time

For a given magnetic head and a given speed of the magnetic medium, the maximum read back voltage is obtained by recording a transition of the signal from point C to D, or D to C, of figure 7-4. Use of the full amplitude capability of the magnetic medium results in the highest signal-to-noise ratio. In addition, since the magnetic recording medium is being saturated, there are no critical bias or record levels to maintain. Most digital systems operate at record head current levels of 125 percent of media saturation or above. Because this level is well above saturation, the exact value is not critical; therefore, no adjustments are required in the recording electronics.

DIGITAL RECORDING TECHNIQUES

Although the characteristics and construction of magnetic drums, tape drives, hard disk units and floppy disk units vary greatly, the fundamental recording process in each is digital. In each type of unit, a magnetic medium is moved past a read-write head. In the write mode, cells of data are recorded. Three basic techniques are used: return-to-zero (rz), return-to-bias (rb), and non-return-to-zero (nrz). In the read mode, the cells of data induce a current in the read head at flux transition. The methods used for reading information written using these techniques also vary, so we will explain the basics for each technique.

For this explanation, magnetic tape will be the recording medium, as it uses all the basics we wish to cover. The read-write head used for this explanation is shown in figure 7-12. Note that it has a separate read winding and a write 1 and write 0 winding.

Return-to-zero (rz)

In a return-to-zero system, the magnetic field of the record head returns to zero flux when a 1 or 0 is not present. This makes it impossible to write over previously written information unless the cell position is very accurately located. Timing for rewriting of data is very critical for this system and must be accurately established by a separate timing track.

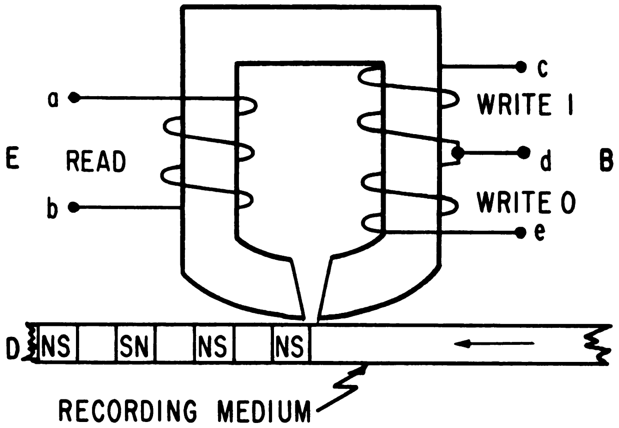

Figure 7-12.—Typical read-write head.

Take a close look at figures 7-12 and 7-13. In figure 7-12, points B, D, and E correspond to figure 7-13 lines B, D, and E. In figure 7-13, line A is the digital data and line B is the write head current. Let +1 represent positive tape saturation and −1 negative saturation; thus, a +1 is applied to WRITE 1 and −1 is applied to WRITE 0 in figure 7-12. The resulting recorded flux pattern is line C. The magnetic cells with a +1 or WRITE 1, designated NS, and −1 or WRITE 0, designated SN, are shown in D of figures 7-12 and 7-13. When these cells pass over the head in the read mode, a current is induced in the read windings with an N transition producing +V, and an S transition producing −V. These are shown on line E. The system timing track sync pulses are included for reference on line F.

The waveforms in figure 7-13 illustrate typical signals. The digital data, line A, is applied to the write head as a square wave at WRITE 1 and WRITE 0 in line B. There is some distortion due to fringing flux around the head and rise and fall time effects. Line C illustrates the remnant flux pattern after writing. Notice that the read waveform in line E is quite different from the square wave initially stated within line B. The flux transitions have been shown widely spaced with no interaction. But in

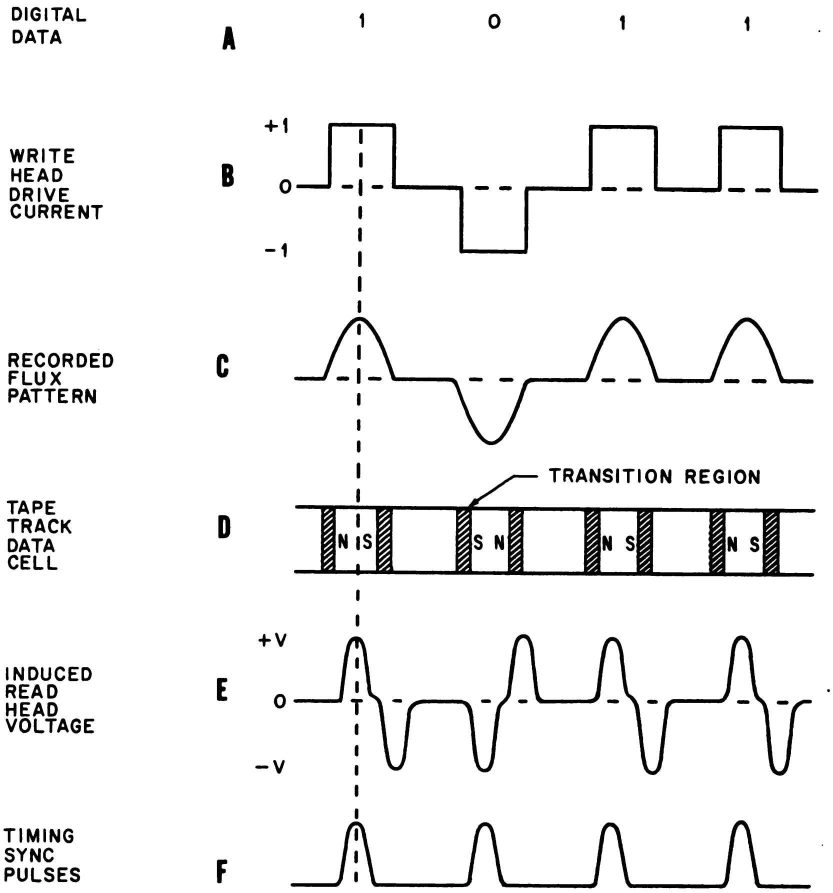

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Figure 7-13.—Rz digital recording.

order to achieve maximum storage density and highest data transfer rates, the flux transitions are written close together and are not infinitely narrow. When two closely spaced transitions are read, the resulting waveform is somewhat like half of a sine wave, as illustrated in figure 7-14. The recorded saturation current is 1_S. The read voltages which would occur if the transitions were widely spaced are e_1 and e_2. The actual resultant read voltage is e_R, due to the close spacing of the transitions. Since the edges of one pulse overlap into areas occupied by adjacent pulses, there is a reduction in amplitude of each pulse. This phenomenon is called "pulse crowding" and causes peak shift. Peak shift is a shift in the position on the peak of the pulse. T is the peak for widely spaced transitions, and T′ is the result of peak shift.

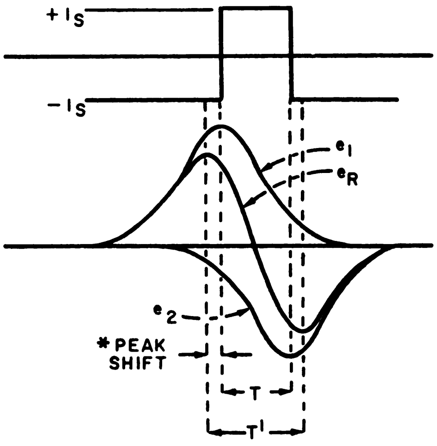

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Figure 7-14.—Merging of transitions.

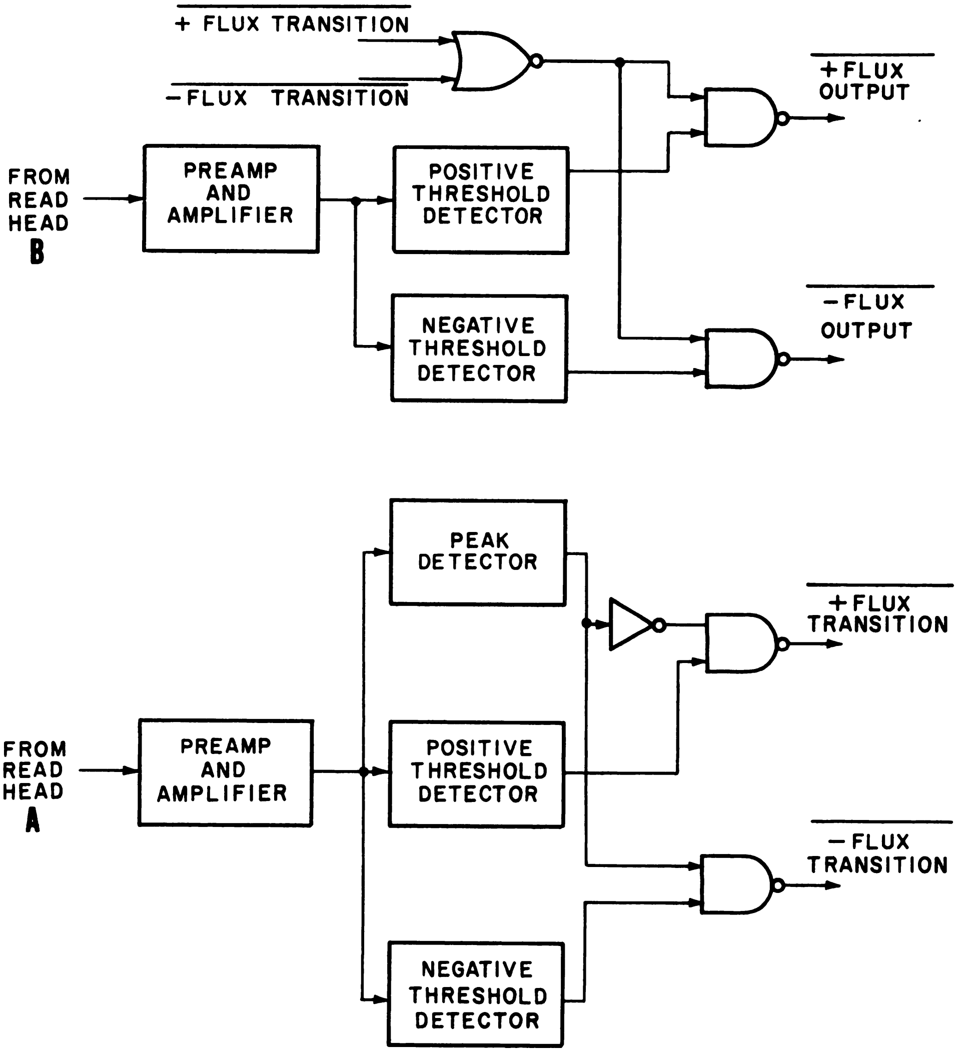

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Figure 7-15.—Typical read head electronics.

Figure 7-15 is a simplified block diagram typical of the electronics needed to derive a true digital signal back from the read sense windings. The lower diagram is typical of what is needed for signal track operation. In multitrack operation, the signal from read head A would be the timing and sync track. The upper diagram is similar to the lower diagram except that the gating occurs from sync generated in the lower diagram. Read head B represents one of the many tracks that are used. Since both diagrams are essentially the same, only the lower will be discussed. A low noise preamp and amplifier bring the signal, which is basically analog, up to the levels needed for operation of threshold and peak detectors. The threshold detectors give an output when there is sufficient + or − voltage. This effectively handles the amplitude variations. However, the amplitude variations cause the width of the detector pulses to vary, and would cause jitter in the outputs. To counter this problem, the signals are gated with the peak detector, to produce combined output

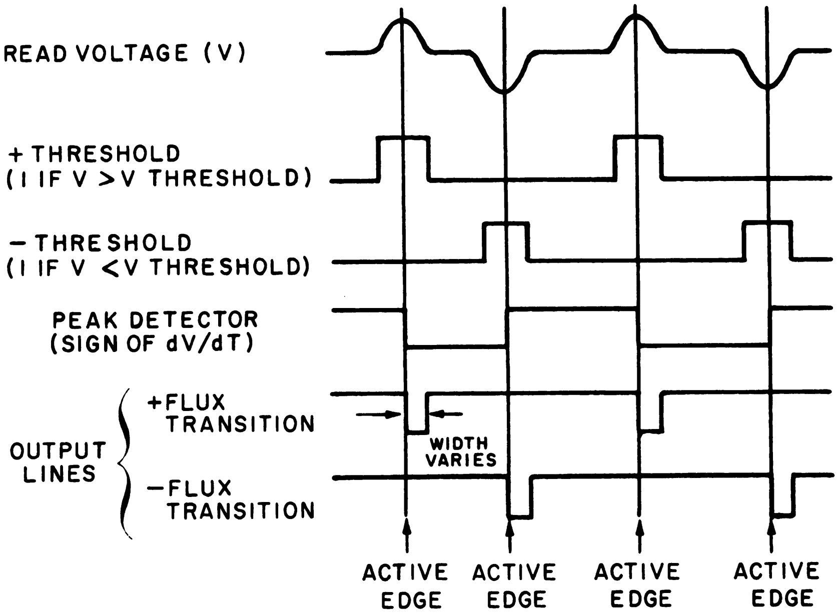

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Figure 7-16.—Sequence of events.

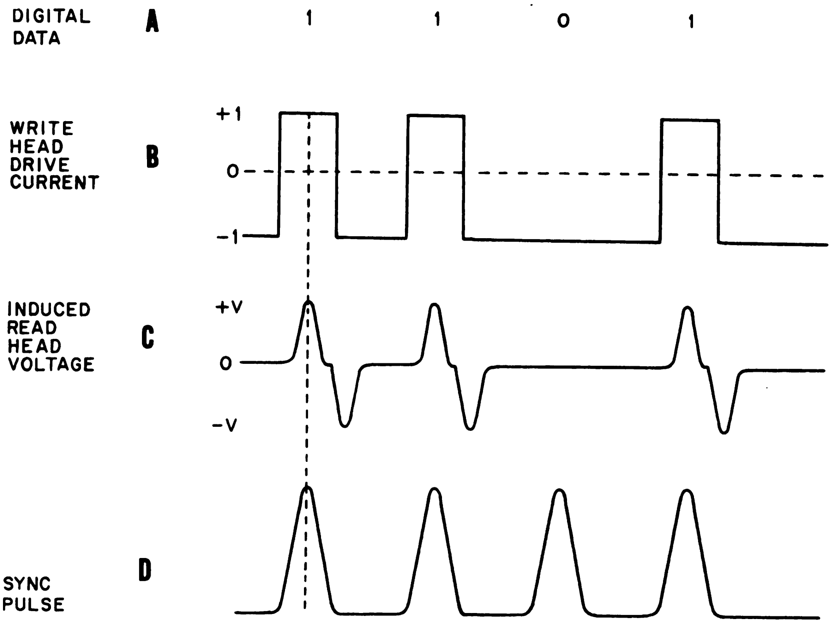

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Figure 7-17.—RB digital recording.

with a stable active leading edge. Figure 7-16 shows the sequence of events just discussed.

Return-to-bias (rb)

The return-to-bias technique is illustrated in figure 7-17. Line A is the data, and line B is the signal to the write head. Terminals c and e would be used; the recording medium would be left to right, NS-NS-SN-NS, for the data 1101. Bias in this case will hold the head in the negative direction unless a 1 is written. Line C is the resulting read signal versus the sync signal on line D. Timing is not as critical when rewriting over old data because the negative flux will magnetize the recording medium in the proper direction regardless of the previous data recorded. Notice that only 1's generate flux changes, so a sync or timing track must be used to prevent problems with a sequence of 0's. In a multitrack system at least one track must have a 1 in each time frame.

Non-return-to-zero (nrz)

The non-return-to-zero (nrz) technique is classified according to three types, which are illustrated in figure 7-18.

In type 1, the head current is constant through the entire bit time. When a 0 is recorded, the current is negative and is positive for a 1. The current remains constant for a series of 0's or 1's and will change only when a 0 is followed by a 1 in the next bit or vice versa.

Type 2 is nrzi, referred to as "modified non-return-to-zero" and "non-return-to-zero mark." In nrzi, polarity has no meaning. The polarity of the write current is reversed each time a 1 is recorded and remains constant when a 0 or a series of 0's are recorded. Notice that the read signal shows transitions only when 1's are recorded. This type must have a timing track with a sequence of 1's; or in a multitrack system, at least one of the bit cells must be a 1.

The third nrz type shown in Biphase Mark, also known as the "phase-encoded," "Harvard," "Manchester" or "split frequency" system. In this technique, a 1/2 bit-time negative pulse followed by a 1/2 bit-time positive pulse is a 0. A 1 is recorded as a 1/2 bit-time positive pulse followed by a 1/2 bit-time negative pulse. This type of nrz is often used in high speed systems.

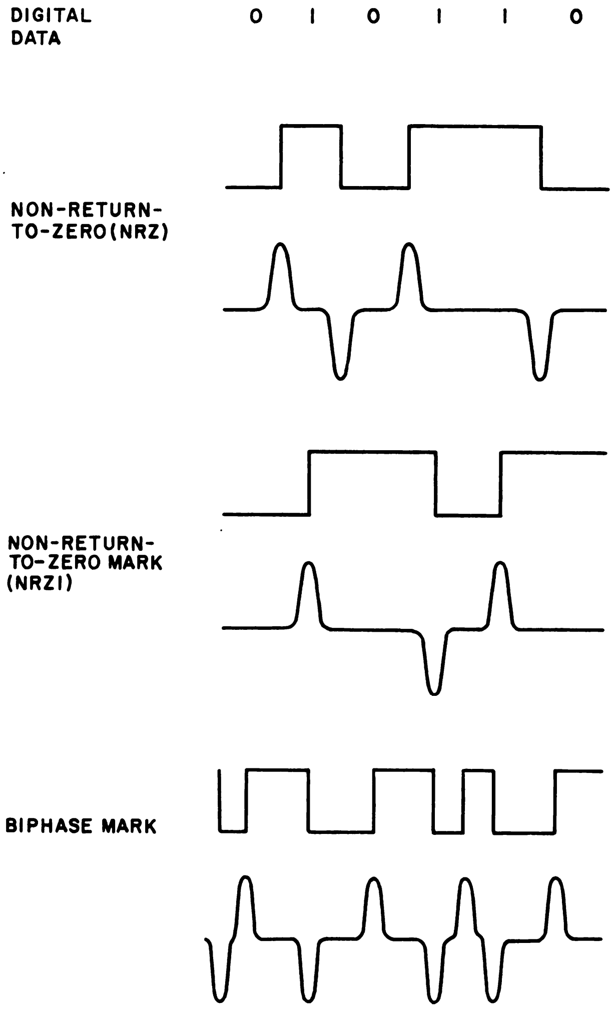

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Figure 7-18.—NRZ digital recording.

In nrz systems, the data must first be brought up to digital signals as covered previously, then translated further by logic circuitry. The additional logic circuitry ranges from a few buffers, gates, and flip-flops to a software program in a computer.

ERASING

The erase process for digital recording is simple; a dc current is applied to the erase head and the recording medium is saturated in one direction. Digital erase heads are usually called "tunnel" or "saddle erase" heads. The erase heads erase a wider track than the read-write head uses.

For digital head care, refer to the section on head care in this chapter. The specialized care of heads used on disks and drums should be accomplished in accordance with individual maintenance manuals.

Magnetic recorders are made, as we have already said, in an infinite variety of configurations. However, once you are acquainted with the general theory, you should be able to adapt to almost any magnetic recorder without much difficulty.

APPENDIX I

GLOSSARY

ABSORPTION FREQUENCY METER (WAVE-METER)—A frequency-measuring device incorporating a variable-tuned circuit which absorbs a small portion of the radiated energy under measurement.

AMBIENT CONDITIONS—Physical conditions of the immediate environment; may pertain to temperature, humidity, pressure, etc.

AND GATE—A logic circuit having multiple inputs and a single output, so designed that the output is energized when (and only when) every input is in the prescribed signal state.

A-SCAN (A-DISPLAY)—In radar, a display in which targets appear as vertical displacements from a line representing the time base. Target distance is represented by the horizontal distance from one end of the time base. Amplitude of the vertical deflection is a function of the signal intensity.

AVB—Avionic Bulletin.

AVC—Avionic Change.

BALLISTICS—The term which refers to the science of the motion of projectiles or bombs.

BEAM WIDTH—The width of an electromagnetic beam, measured in degrees on an arc which lies in a plane along the axis of propagation, between points of equal field strength. It may be measured in the horizontal or vertical plane.

BIAS—In vacuum tubes, the difference of potential between the control grid and the cathode; in transistors, the difference of potential between the base and emitter and between the base and collector; in magnetic amplifiers; the level of flux density in the core under no-signal conditions.

BOLOMETER—A small resistive element used in the measurement of low and medium RF power. It is characterized by a large temperature coefficient of resistance which is capable of being properly matched to a transmission line.

BRIDGE CIRCUIT—The electrical bridge circuit is a term referring to any one of a variety of electric circuit networks, one branch of which, the "bridge" proper, connects two points of equal potential and hence carries no current when the circuit is properly adjusted or balanced.

B-SCAN (B-DISPLAY)—In radar, a rectangular display in which targets appear as illuminated areas, with bearing indicated by the horizontal coordinate and distance by the vertical coordinate.

CAVITY RESONATOR—A hollow metallic cavity in which electromagnetic oscillation can exist when the cavity is properly excited.

CHARACTERISTIC (ITERATIVE) IMPEDANCE—The apparent load presented to a source; in electronics the characteristic impedance at any frequency range is approximately equal to the ratio of the inductance to the capacitance.

COMPARATOR—A circuit which compares two signals or values, and indicates agreement or variance between them.

CONTROL CIRCUITS—In computers, those circuits involved in the carrying out of the program instructions.

COUNTING CIRCUIT—A circuit which receives uniform pulses representing units to be counted and produces a voltage in proportion to their frequency.

DIRECTIONAL COUPLER—A device used to extract a portion of the RF energy moving in a given direction in a transmission line or waveguide. Energy moving in the opposite direction is rejected.

DISCRIMINATOR—A dual-input circuit in which the output is dependent on the variation of one input from the other input or from an applied standard.

DIURNAL—Having a daily cycle. Recurring every day.

DRIFT—Net change in characteristics of electronic components or parameters, resulting from external or incidental conditions.

DUPLEXER—A switch or tube which permits the use of a single antenna for both transmission and reception. The dual function of the duplexer is to prevent absorption of transmitter energy by the receiver system (thereby protecting the receiver), and to prevent absorption of any appreciable portion of the received echo signal by the transmitter.

ECHO BOX—A high-Q resonant cavity used with microwave radar sets to provide artificial targets for radar testing and for tuning the receiver to the transmitter. The echo box stores RF energy during the transmitted-pulse interval, and reradiates it through the same antenna for a short time following the pulse.

ELECTROLYSIS—A type of corrosion (chemical, decomposition) caused by current flow resulting from contact of dissimilar metals.

EQUIVALENT CIRCUIT—A diagrammatic arrangement of component parts, representing in simplified form the effects of a more complicated circuit, to permit easier analysis.

ERASING HEAD—A device which removes stored data from the surface of a magnetic storage material.

FEEDBACK—The return of a portion of the output of a circuit stage to the input of that stage or a preceding stage, such that there is either an increase (regeneration) or a reduction (degeneration) in amplification, depending on the relative phase of the returned signal with the input.

FERRITE—A hard and brittle crystalline substance made from a mixture of powdered materials including iron oxides; it has special magnetic properties of particular value in computers and in many other applications.

FULL ADDER—An adder circuit which can complete the adding procedure involving the carry process, as distinguished from the half adder which is not capable of accepting a previous carry.

GATING CIRCUIT (GATE)—A circuit used to activate (or deactivate) another circuit by permitting (or prohibiting) operation during selected periods of time.

GROUND SUPPORT EQUIPMENT—See Support Equipment.

HALF ADDER—A partial adding circuit which is not capable of accepting a previous carry. It must be combined with another half adder and a circuit capable of performing the carry function to form a full adder.

HERTZ—A unit of frequency equal to one cycle per second.

HMI—Handbook Maintenance Instructions.

HYSTERESIS—A lagging of the magnetic flux in a magnetic material behind the magnetizing force which is producing it.

Hz—Cycles per second.

INHIBITORY PULSE—A pulse which acts to inhibit or suppress another signal from going through a logic circuit and appearing at the output.

INTEGRATING CIRCUIT—A circuit whose output voltage is proportional to the product of the instantaneous applied input voltages and their durations.

INTEGRATOR—A computing device used for summing up an infinite number of minute quantities.

MAGNETRON—A microwave oscillator which utilizes an electron tube (consisting of a cathode and an anode), a strong axial magnetic field, and resonant cavities.

MAGNETRON ARCING—Internal breakdown between cathode and anode of a magnetron, usually resulting from presence of gas. Occurs during the breaking-in, or "seasoning" period and again at the end of the useful life. Occasional arcing is common, especially in high power magnetrons.

MAGNETRON PULLING—The frequency shift of a magnetron resulting from a mismatch at the output. It is caused by such factors as faulty rotating joints, reflections from objects near the antenna, etc.

MAGNETRON PUSHING—The frequency shift of a magnetron resulting from faulty operation of the modulator. It may result from an improperly shaped pulse or from interaction of the pulse with the magnetic field.

MASTER CLOCK—The timed and synchronized generators which comprise the source and time reference for computer signals.

MEGOHM—A million ohms.

MEMORY UNIT—In computers, a device used for storing data for possible use in computation.

MICROWAVES—A term commonly used to indicate electromagnetic waves in the frequency range between 1,000 and 300,000 megahertz (30 cm to 1 mm).

MONOPULSE—A method of antenna lobing which permits information to be obtained on target range, bearing, and elevation from a single pulse (as distinguished from sequential lobing).

NOISE—Any undesired disturbance within the useful frequency band; also, that part of the modulation of a received signal (or an electrical or electronic signal within a circuit) representing an undesirable effect of transient conditions.

NOT CIRCUIT—In computers, a circuit in which the output signal does not have the same polarity as the input signal. A phase inverter.

NULL—A point or position where a variable-strength signal is at its minimum value (or zero).

OR GATE—A logic circuit having multiple inputs and a single output, so designed that the output is energized when any one or more of the inputs are in the prescribed signal state.

PARALLEL MODE—In computer operation, the handling of a group of numbers or other symbols simultaneously.

PARAMETERS—In electronics, the design or operating characteristics of a circuit or device.

POLARIZATION—In electronics, a term used in specifying the direction of the electric vector in a linearly polarized electromagnetic wave as radiated from a transmitting antenna, or as picked up by a receiving antenna.

POTENTIOMETER—A variable voltage divider; a resistor which has a variable contact arm so that any portion of the potential applied between its ends may be selected.

PPI-SCAN (PPI DISPLAY)—A cathode-ray tube presentation in which the signal appears on a rotating radial line. Distance is indicated radially, and bearing as an angle.

PROGRAM—In computers, a complete set of "word" instructions indicating the sequential order which the computer must follow in solving a particular problem.

PROPAGATION—Extending the action of, transmitting, carrying forward as in space or time or through a medium (as the propagation of sound, light, or radio waves).

PULSE TRAIN—A series of pulses passed through a circuit as control or information signals.

REGISTER—A specific computer unit which stores a single computer word.

RESONANT CAVITY—A space, normally enclosed by an electrically conductive surface, in which oscillatory electromagnetic energy is stored, and whose resonant frequency is determined primarily by the geometry of the enclosure.

RING TIME—In radar, the time during which the output of an echo box remains above a predetermined level; used in measuring the performance of radar equipment.

SEQUENTIAL LOBING—Successively shifting the radar beam about the scanner centerline through a particular pattern; differs from monopulse.

SERIAL OPERATION—In computers, the sequential handling of a group of numbers or symbols.

SHIFT REGISTER—In computers, a circuit which will shift a digit or a group of digits either to the left or to the right; it is of particular importance in some multiplication and division processes, and in sequential storage of pulse trains.

SLEW—To change the position of an indicator mark on a CRT display by varying the time relationship of the mark with respect to the start of the sweep.

SUPPORT EQUIPMENT (SE)—All the equipment on the ground or ship needed to support aircraft in a state of readiness for flight. Previously known as Ground Support Equipment (GSE).

THERMISTOR—A bolometer characterized by a decrease of resistance as the temperature rises. (See also Bolometer.)

TRIGGERING—Starting an action in another circuit, which then operates for a time under its own control.

WAVEGUIDE—Metal tubes or dielectric cylinders capable of propagating electromagnetic waves through their interiors. The dimensions of these devices are determined by the frequency to be propagated. Metal guides are usually rectangular or circular in cross section; they may be evacuated, air filled, or gas filled, and may or may not be pressurized. Dielectric guides consist of solid dielectric cylinders surrounded by air.

APPENDIX II

SYMBOLS

ADJUSTABILITY (1)

physically adjustable, variable

preset

linear (shown applied)

nonlinear (shown applied)

inherent variability

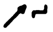
linear

nonlinear

special features (shown applied)

continuous

in steps

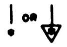


CIRCUIT RETURN (13)

earth ground

chassis connection

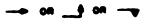
common connections



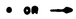
(identification tying points together replaces (*))

CONTACT, ELECTRICAL (23)

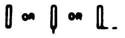
fixed, for jack, key, relay, etc.



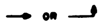
fixed, for switch



sleeve



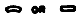
adjustable, for resistor, inductor, etc.



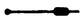
moving, locking

moving, nonlocking

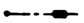
segment; bridging



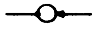
vibrator reed



vibrator split reed

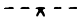


slip ring and brush



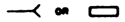
CONNECTION; INTERLOCK (17) (MECHANICAL)

with fulcrum

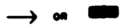


CONNECTOR (18)

female



male



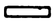
CORE (25

no core (air)

NO SYMBOL

magnetic core of inductor or transformer

core of magnet



COUPLING (28)

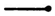
(common coaxial/waveguide usage)

by aperture

(E, H or HE coupling indicators replace (*) asterisk)

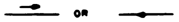
by loop to space

by probe to space

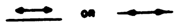


DIRECTION OF FLOW (32)

one way



both ways



ELECTRON TUBE ELEMENTS (34)

directly-heated cathode; heater; filament

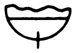
heater with tap

indirectly heated cathode

cold cathode (also ionically heated cathode)

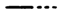
photocathode

pool cathode



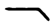
ionically heated cathode with supplementary heating

grid



deflecting electrode

igniter (pool tubes); starter (gas tubes)



excitor (contacting)

anode or plate

target or x-ray anode

dynode

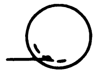
composite anode-photo-cathode

composite anode-cold cathode

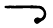
composite anode-ionically heated cathode with supplementary heating

envelope
(see ENVELOPE ENCLOSURE)

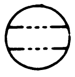
shield, with external connection



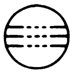
coupling by loop



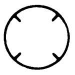
single cavity resonator (envelope) with grids



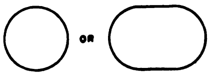
double cavity resonator (envelope) with grids



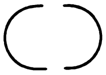
multicavity magnetron anode (and envelope)



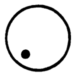
ENVELOPE ENCLOSURE (35)
(capacitor, electron tube, relay, etc.)



split



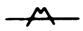
gas-filled



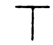
GROUND (38)
(See CIRCUIT RETURN)

MAGNET, PERMANENT (47)

MODE SUPPRESION (52)
(common coaxial/waveguide usage)



MODE TRANSDUCER (53)
(common coaxial/waveguide usage)



MOTION, MECHANICAL (54)

translation, one direction

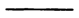
translation, both directions

rotation, one direction

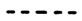
rotation, both directions

PATH, TRANSMISSION (58)

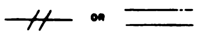
general; wire; guided



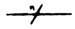
associated/future



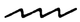
two conductors



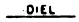
η conductors



air or space path



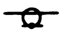
dielectric path other than air (common coaxial/waveguide usage)



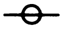
path crossing, not connected

path junction; connection

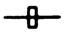
coaxial cable



circular waveguide



rectangular waveguide



POLARITY (63)

positive

+

negative

–

RADIATION-SENSITIVITY INDICATOR (69)

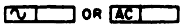
non-ionizing electromagnetic radiation (radio waves, infrared, visible and ultraviolet light)

ionizing electromagnetic radiation (x-rays, gamma rays)

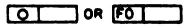
ionizing particulate radiation (beta rays, alpha rays, protons and neutral particles)

RELAY COIL RECOGNITION (66)

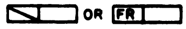
a-c or ringing



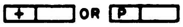
fast-operate



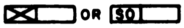
fast-release



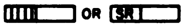
magnetically polarized



slow-operate



slow-operate and slow release



Relay Letter Combinations

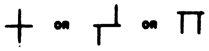
D	Differential
DB	Double biased
DP	Dashpot
EP	Electrically polarized
MG	Marginal
NB	No bias
NR	Nonreactive
SA	Slow operate and slow release
SW	Sandwich wound

RESONATOR, TUNED CAVITY (71)
(common coaxial/waveguide usage)

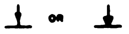
SEMICONDUCTOR ELEMENTS, TRANSISTOR (73)

region with one ohmic connection

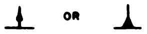
region with plurality of ohmic connections



rectifying junction, P on N region



rectifying junction, N on P region



emitter, P on N region

emitter, N on P region

collector

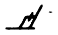
transition between regions of dissimilar conductivity

intrinsic region between regions of dissimilar conductivity

intrinsic region between regions of similar conductivity

intrinsic region between collector and region of dissimilar conductivity

intrinsic region between collector and region of similar conductivity



temperature dependance

t°

capacitive action

tunneling action

]

breakdown action

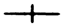
J

SHIELD(ING) (74)

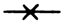
— — — — —

SWITCHING FUNCTION (77)

conducting, closed contact (break)



nonconducting, open (make)

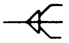


TERMINAL, CIRCUIT (80) (common indication of included pin or screw connections of bases and strips for electron tubes, semiconductors, plug-in capacitors and relays, terminal boards, item parts, etc.)

o

TERMINATION (82)

cable termination

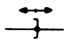


all below are common coaxial/waveguide indicators

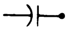
open circuit, not a fault

short circuit, not a fault

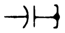
movable short



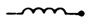
series capacitor and path open



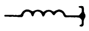
series capacitor and path shorted



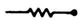
series inductor and path open



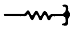
series inductor and path shorted



series resistor and path open

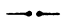


series resistor and path shorted

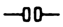


ARRESTER, LIGHTNING (4)

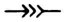
general



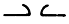
carbon block



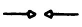
electrolytic or aluminum cell



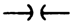
horn gap



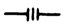
protective gap



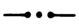
sphere gap



valve or film element



multigap

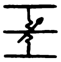


ATTENUATOR, FIXED (see PAD) (57)

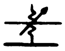
(same symbol as variable attenuator, without variability)

ATTENUATOR,VARIABLE (5)

balanced



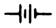
unbalanced



BATTERY (7)

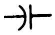
generalized direct current source; one cell

multicell

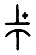


CAPACITOR (8)

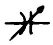
general



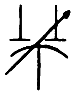
polarized



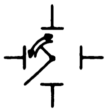
adjustable or variable



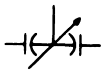
continuously adjustable or variable differential



phase-shifter



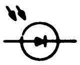
split-stator



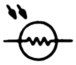
feed-through

CELL, PHOTOSENSITIVE (Semiconductor) (9)

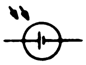
asymmetrical photoconductive transducer



symmetrical photoconductive transducer

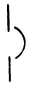


photovoltaic transducer; solar cell



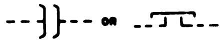
CIRCUIT BREAKER (11)

general

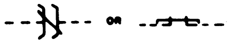


CLUTCH; BRAKE (14)

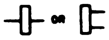
disengaged when operating means is de-energized



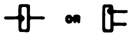
engaged when operating means is de-energized



COIL, RELAY and OPERATING (16)

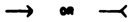


semicircular dot indicates inner end of wiring

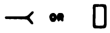


CONNECTOR (18)

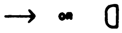
assembly, movable or stationary portion; jack, plug, or receptacle



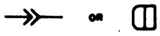
jack or receptacle



plug

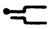


separable connectors

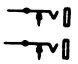


two-conductor switchboard jack

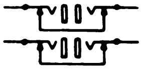
two-conductor switchboard plug



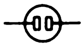
jacks normalled through one way



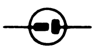
jacks normalled through both ways



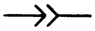
2-conductor nonpolarized, female contacts



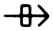
2-conductor polarized, male contacts



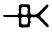
waveguide flange



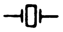
plain, rectangular



choke, rectangular

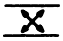


CRYSTAL, PIEZO-ELECTRIC (62)



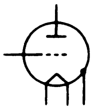
COUPLER,DIRECTIONAL (27)

(common coaxial/waveguide usage)

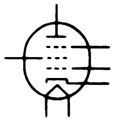


ELECTRON TUBE (34)

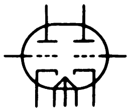
triode



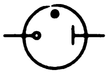
pentode, envelope connected to base terminal



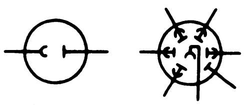
twin triode, equipotential cathode



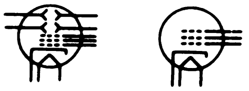
rectifier; voltage regulator
(see LAMP, GLOW)



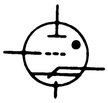
phototube, single and multiplier



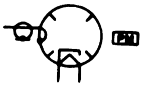
cathode-ray tube, electrostatic and magnetic deflection



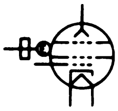
mercury-pool tube, ignitor and control grid (see RECTIFIER)



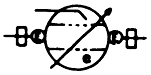
resonant magnetron, coaxial output and permanent magnet



reflex klystron, integral cavity, aperture coupled

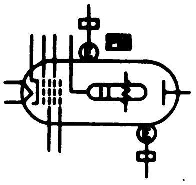


transmit-receive (TR) tube gas filled, tunable integral cavity, aperture coupled, with starter



traveling-wave tube (typical)

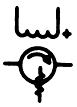
forward-wave traveling-wave-tube amplifier shown with four grids, having slow-wave structure with attenuation, magnetic focusing by external permanent magnet, rf input and rf output coupling each E-plane aperture to external rectangular waveguide



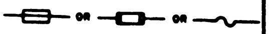
FERRITE DEVICES (100)

field polarization rotator

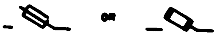
field polarization amplitude modulator



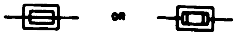
FUSE (36)



high-voltage primary cutout, dry

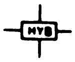


high-voltage primary cutout, oil

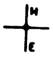


HYBRID (41)

general



junction
(common coaxial/waveguide usage)

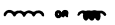


circular

(E, H or HE transverse field indicators replace (*) asterisk)

INDUCTOR (42)

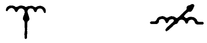
general



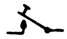
magnetic core

tapped

adjustable, continuously adjustable

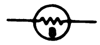


KEY, TELEGRAPH (43)

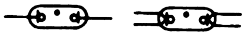


LAMP (44)

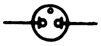
ballast lamp; ballast tube



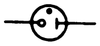
lamp, fluorescent, 2 and 4 terminal



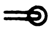
lamp, glow; neon lamp
a-c



d-c

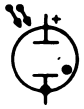


lamp, incandescent



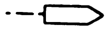
indicating lamp; switchboard lamp
(see VISUAL SIGNALING DEVICE)

NUCLEAR-RADIATION DETECTOR, gas filled; IONIZATION CHAMBER; PROPORTIONAL COUNTER TUBE; GEIGER-MULLER COUNTER TUBE (50)
(see RADIATION-SENSITIVITY INDICATOR)

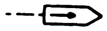


PICKUP HEAD (61)

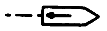
general



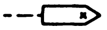
writing; recording



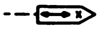
reading; playback



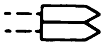
erasing



writing, reading, and erasing

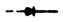


stereo

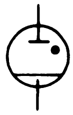


RECTIFIER (65)

semiconductor diode; metallic rectifier; electrolytic rectifier; asymmetrical varistor

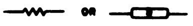


mercury-pool tube power rectifier

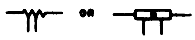


RESISTOR (68)

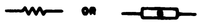
general



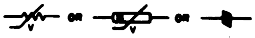
tapped



heating



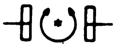
symmetrical varistor resistor, voltage sensitive (silicon carbide, etc.)



(identification marks replace (*) asterisk)

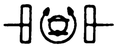
ROTARY JOINT, RF (COUPLER) (72)

general; with rectangular waveguide

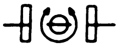


(transmission path recognition symbol replaces (*) asterisk)

coaxial type in rectangular waveguide

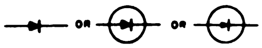


circular waveguide type in rectangular waveguide

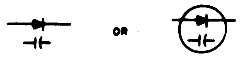


SEMICONDUCTOR DEVICE (73)
(Two Terminal, diode)

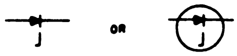
semiconductor diode; rectifier



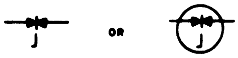
capacitive diode (also Varicap, Varactor, reactance diode, parametric diode)



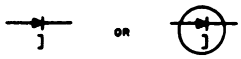
breakdown diode, unidirectional (also backward diode, avalanche diode, voltage regulator diode, Zener diode, voltage reference diode)



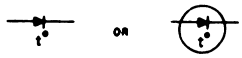
breakdown diode, bidirectional and backward diode (also bipolar voltage limiter)



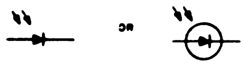
tunnel diode (also Esaki diode)



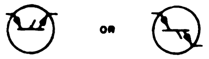
temperature-dependent diode



photodiode (also solar cell)

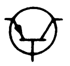


semiconductor diode, PNPN switch (also Shockley diode, four-layer diode)

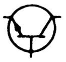


(Multi-Terminal, transistor, etc.)

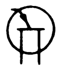
PNP transistor



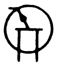
NPN transistor



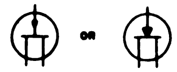
unijunction transistor, N-type base



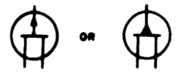
unijunction transistor, P-type base



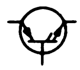
field-effect transistor, N-type base



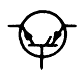
field-effect transistor, P-type base



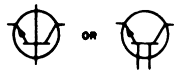
semiconductor triode, PNPN-type switch



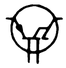
semiconductor triode, NPNP-type switch



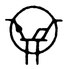
NPN transistor, transverse-biased base



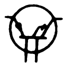
PNIP transistor, ohmic connection to the intrinsic region



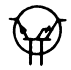
NPIN transistor, ohmic connection to the intrinsic region



PNIN transistor, ohmic connection to the intrinsic region

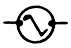


NPIP transistor, ohmic connection to the intrinsic region

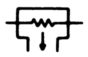


SQUIB (75)

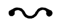
explosive



igniter

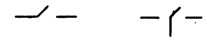


sensing link; fusible link operated.

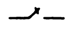


SWITCH (76)

general, single and double throw



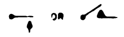
knife



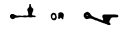
push button, circuit closing (make)

push button, circuit opening (break)

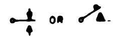
nonlocking; momentary circuit closing (make)



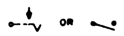
nonlocking; momentary circuit opening (break)



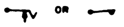
transfer



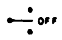
locking, circuit closing (make)



locking, circuit opening (break)

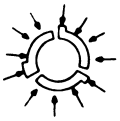


transfer, 3-position

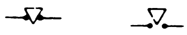


wafer

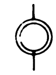
(example shown: 3-pole 3-circuit with 2 non-shorting and 1 shorting moving contacts)



safety interlock, circuit opening and closing



SYNCHRO (78)

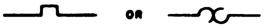


Synchro Letter Combinations

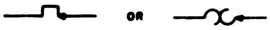
CDX	Control-differential transmitter
CT	Control transformer
CX	Control transmitter
TDR	Torque-differential receiver
TDX	Torque-differential transmitter
TR	Torque receiver
TX	Torque transmitter
RS	Resolver
B	Outer winding rotatable in bearings

THERMAL ELEMENT (83)

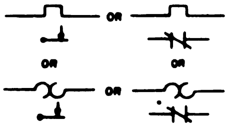
actuating device



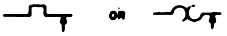
thermal cutout; flasher



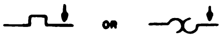
thermal relay



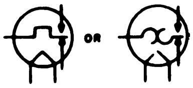
thermostat (operates on rising temperature), contact)



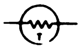
thermostat, make contact



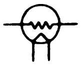
thermostat, integral heater and transfer contacts



THERMISTOR; THERMAL RESISTOR (84)

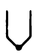


with integral heater

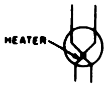


THERMOCOUPLE (85)

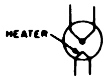
temperature-measuring



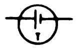
current-measuring, integral heater connected



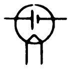
current-measuring, integral heater insulated



temperature-measuring, semiconductor

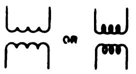


current-measuring, semiconductor

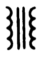


TRANSFORMER (86)

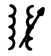
general



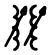
magnetic-core



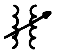
one winding with adjustable inductance



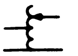
Separately adjustable inductance



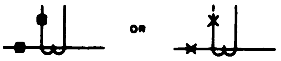
adjustable mutual inductor, constant-current



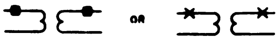
autotransformer, 1-phase adjustable



current, with polarity marking

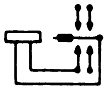


potential, with polarity mark

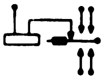


VIBRATOR; INTERRUPTER (87)

typical shunt drive (terminals shown)

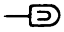


typical separate drive (terminals shown)

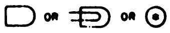


VISUAL SIGNALING DEVICE (88)

communication switchboard-type lamp



indicating, pilot, signaling, or switchboard light (see LAMP)



(identification replaces (*) asterisk)

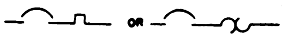
indicating light letter combinations

A	Amber
B	Blue
C	Clear
G	Green
NE	Neon
O	Orange
OP	Opalescent
P	Purple
R	Red
W	White
Y	Yellow

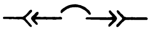
jeweled signal light

CIRCUIT BREAKER (11)

with magnetic overload

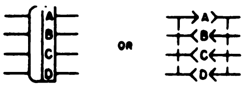


drawout type

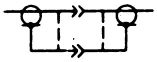


CONNECTOR (18)

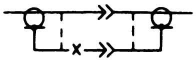
engaged 4-conductor; the plug has 1 male and 3 female contacts, individual contact designations shown



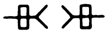
coaxial, outside conductor shown carried through



coaxial, center conductor shown carried through; outside conductor not carried through



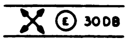
mated choke flanges in rectangular waveguide



COUPLER, DIRECTIONAL (27)

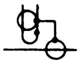
(common coaxial/waveguide usage)

E-plane aperture-coupling, 30-decibel transmission loss



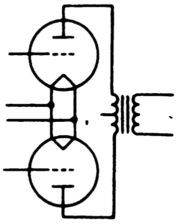
COUPLING (28)

by loop from coaxial to circular waveguide, direct-current grounds connected



ELECTRON TUBE (34)

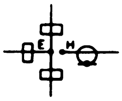
typical wiring figure to show tube symbols placed in any convenient position



HYBRID (41)

(common coaxial/waveguide usage)

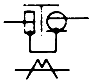
rectangular waveguide and coaxial coupling



MODE TRANSDUCER (53)

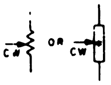
(common coaxial/waveguide usage)

transducer from rectangular waveguide to coaxial with mode suppression, direct-current grounds connected



MOTION, MECHANICAL (54)

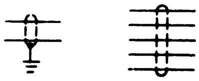
rotation applied to a resistor



(identification replaces (*) asterisk)

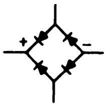
PATH, TRANSMISSION (58)

cable; 2-conductor, shield grounded and 5-conductor shielded



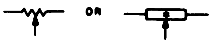
RECTIFIER (65)

fullwave bridge-type

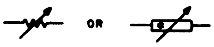


RESISTOR (68)

with adjustable contact



adjustable or continuously adjustable (variable)

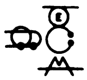


(identification replaces (*) asterisk)

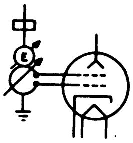
RESONATOR, TUNED CAVITY (71)

(common coaxial/waveguide usage)

resonator with mode suppression coupled by an E-plane aperture to a guided transmission path and by a loop to a coaxial path

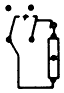


tunable resonator with direct-current ground connected to an electron device and adjustably coupled by an E-plane aperture to a rectangular waveguide



SWITCH (76)

2-pole field-discharge knife, with terminals and discharge resistor

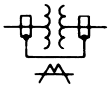


(identification replaces (*) asterisk)

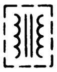
TRANSFORMER (86)

with direct-current connections and mode suppression between two rectangular waveguides

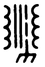
(common coaxial/waveguide usage)



shielded, with magnetic core

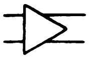


with a shield between windings, connected to the frame

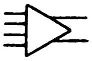


AMPLIFIER (2)

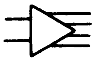
general



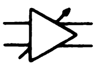
with two inputs



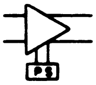
with two outputs



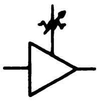
with adjustable gain



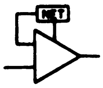
with associated power supply



with associated attenuator



with external feedback path

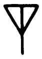


Amplifier Letter Combinations (amplifier-use identification in symbol if required)

BDG	Bridging
BST	Booster
CMP	Compression
DC	Direct Current
EXP	Expansion
LIM	Limiting
MON	Monitoring
PGM	Program
PRE	Preliminary
PWR	Power
TRQ	Torque

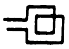
ANTENNA (3)

general



dipole

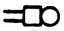
loop



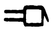
counterpoise

AUDIBLE SIGNALING DEVICE (6)

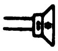
bell, electrical; ringer, telephone



buzzer



horn, electrical; loudspeaker; siren; underwater sound hydrophone, projector or transducer



Horn, Letter Combinations. (if required)

*HN	Horn, electrical
*HW	Howler
*LS	Loudspeaker
*SN	Siren
‡EM	Electromagnetic with moving coil
‡EMN	Electromagnetic with moving coil and neutralizing winding
‡MG	Magnetic armature
‡PM	Permanent magnet with moving coil

identification replaces (*) asterisk and (‡) degger)

sounder, telegraph

CIRCUIT ELEMENT (12)

general

Circuit Element Letter Combinations (replaces (*) asterisk)

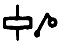
EG	Equalizer
FAX	Facsimile set
FL	Filter
FL-BE	Filter, band elimination
FL-BP	Filter, band pass
FL-HP	Filter, high pass
FL-LP	Filter, low pass
PS	Power supply
RG	Recording unit
RU	Reproducing unit
DIAL	Telephone dial
TEL	Telephone station
TPR	Teleprinter
TTY	Teletypewriter

Additional Letter Combinations (symbols preferred)

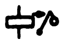
AR	Amplifier
AT	Attenuator
C	Capacitor
CB	Circuit breaker
HS	Handset
I	Indicating or switch board lamp
L	Inductor
J	Jack
LS	Loudspeaker
MIC	Microphone
OSC	Oscillator
PAD	Pad
P	Plug
RT	Receiver, headset
K	Relay
R	Resistor
S	Switch or key switch
T	Transformer
WR	Wall receptacle

COUNTER, ELECTROMAGNETIC; MESSAGE REGISTER (26)

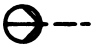
general



with a make contact

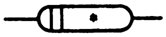


DETECTOR, PRIMARY; MEASURING TRANSDUCER (30) (see HALL GENERATOR and THERMAL CONVERTER)

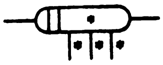


DELAY LINE (31)

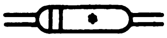
general



tapped delay



bifilar slow-wave structure (commonly used in traveling-wave tubes)

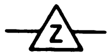


(length of delay indication replaces (*) asterisk)

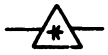
DISCONTINUITY (33)

(common coaxial/waveguide usage)

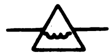
equivalent series element, general



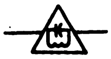
capacitive reactance



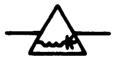
inductive reactance



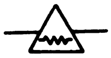
inductance-capacitance circuit, infinite reactance at resonance



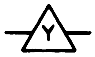
inductance-capacitance circuit, zero reactance at resonance



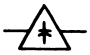
resistance



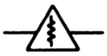
equivalent shunt element, general



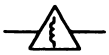
capacitive susceptance



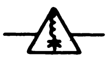
conductance



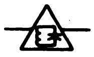
inductive susceptance



inductance-capacitance circuit, infinite susceptance at resonance

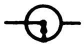


inductance-capacitance circuit, zero susceptance at resonance

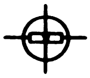


GOVERNOR (Contact-making) (37)

contacts shown here as closed

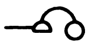


HALL GENERATOR (39)

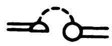


HANDSET (40)

general

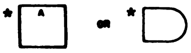


operator's set with push-to talk switch

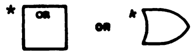


LOGIC (see 806B and Y32-14) (including some duplicate symbols; left and right-hand symbols are not mixed)

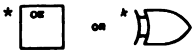
AND function



OR function



EXCLUSIVE-OR function



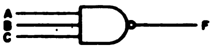
((*) input side of logic symbols in general)

condition indicators

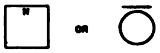
state (logic negation)

a Logic Negation output becomes 1-state if and only if the input is not 1-state

an AND func. where output is low if and only if all inputs are high

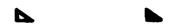


electric inverter



(elec. invtr. output becomes 1-state if and only if the input is 1-state) (elec. invtr. output is more pos. if and only if input is less pos.)

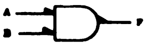
level (relative)



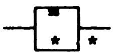
1-state is less + 1-state is more +

(symbol is a rt. triangle pointing in direction of flow)

an AND func. with input 1-states at more pos. level and output 1-state at less pos. level

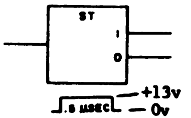


single shot (one output)

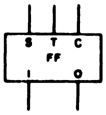


(waveform data replaces inside/outside (*))

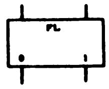
schmitt trigger, waveform and two outputs



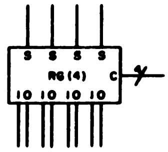
flip-flop, complementary



flip-flop, latch

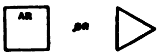


register



(binary register denoting four flip-flops and bits)

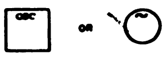
amplifier (see AMPLIFIER)



channel path(s) (see PATH, TRANSMISSION)

magnetic heads (see PICK-UP HEAD)

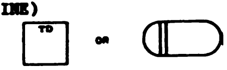
oscillator (see OSCILLATOR)



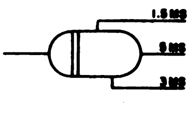
relay, contacts (see CONTACT, ELECTRICAL)
relay, electromagnetic (see RELAY COIL RECOGNITION)

signal flow (see DIRECTION OF FLOW)

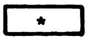
time delay (see DELAY LINE)



time delay with typical delay taps:



functions not otherwise symbolized



(identification replaces (*))

Logic Letter Combinations

S	set
C	clear (reset)
T	toggle (trigger)
(N)	number of bits
BO	blocking oscillator
CF	cathode follower
EF	emitter follower
FF	flip-flop
SS	single shot
ST	schmitt trigger
RG(N)	register (N stages)
SR	shift register

MACHINE, ROTATING (46)

generator

motor

APPENDIX III

U.S. CUSTOMARY & METRIC SYSTEM UNITS OF MEASUREMENT

THESE PREFIXES MAY BE APPLIED TO ALL SI UNITS

Multiples and Submultiples	Prefixes	Symbols
1 000 000 000 000 = 10^{12}	tera (tĕr′ȧ)	T
1 000 000 000 = 10^{9}	giga (jĭ′gȧ)	G
1 000 000 = 10^{6}	mega (mĕg′ȧ)	M*
1 000 = 10^{3}	kilo (kĭl′ō)	k*
100 = 10^{2}	hecto (hĕk′tō)	h
10 = 10	deka (dĕk′ȧ)	da
0.1 = 10^{-1}	deci (dĕs′ĭ)	d
0.01 = 10^{-2}	centi (sĕn′tĭ)	c*
0.001 = 10^{-3}	milli (mĭl′ĭ)	m*
0.000 001 = 10^{-6}	micro (mī′krō)	μ*
0.000 000 001 = 10^{-9}	nano (năn′ō)	n
0.000 000 000 001 = 10^{-12}	pico (pē′kō)	p
0.000 000 000 000 001 = 10^{-15}	femto (fĕm′tō)	f
0.000 000 000 000 000 001 = 10^{-18}	atto (ăt′tō)	a

*Most commonly used

APPENDIX IV

FORMULAS

Ohm's Law for dc Circuits

$$I = \frac{E}{R} = \frac{P}{E} = \sqrt{\frac{P}{R}}$$

$$R = \frac{E}{I} = \frac{P}{I^2} = \frac{E^2}{P}$$

$$E = IR = \frac{P}{I} = \sqrt{PR}$$

$$P = EI = \frac{E^2}{R} = I^2R$$

Resistors in Series

$$R_T = R^1 + R^2 + \dots$$

Resistors in Parallel

Two resistors

$$R_T = \frac{R_1R_2}{R_1 + R_2}$$

More than two

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$

RL Circuit Time Constant

$$\frac{\text{L (in henrys)}}{\text{R (in ohms)}} = \text{t (in seconds), or}$$

$$\frac{\text{L (in microhenrys)}}{\text{R (in ohms)}} = \text{t (in microseconds)}$$

RC Circuit Time Constant

R (ohms) × C (farads) = t (seconds)

R (megohms) × C (microfarads) = t (seconds)

R (ohms) × C (microfarads) = t (microseconds)

R (megohms) × C (micromicrofarads) = t (microseconds)

Capacitors in Series

Two capacitors

$$C_T = \frac{C_1C_2}{C_1 + C_2}$$

More than two

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots$$

Capacitors in Parallel

$$C_T = C_1 + C_2 + \dots$$

Capacitive Reactance

$$X_C = \frac{1}{2\pi fC}$$

Impedance in an RC Circuit (Series)

$$Z = \sqrt{R^2 + (X_C)^2}$$

Inductors in Series

$L_T = L_1 + L_2 + \dots$ (No coupling between coils)

Inductors in Parallel

Two inductors

$$L_T = \frac{L_1L_2}{L_1 + L_2} \text{ (No coupling between coils)}$$

More than two

$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \dots \text{ (No coupling between coils)}$$

Inductive Reactance

$$X_L = 2\pi fL$$

Q of a Coil

$$Q = \frac{X_L}{R}$$

Impedance of an RL Circuit (Series)

$$Z = \sqrt{R^2 + (X_L)^2}$$

Impedance with R, C, and L in Series

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Parallel Circuit Impedance

$$Z = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

Sine-Wave Voltage Relationships

Average value

$$E_{ave} = \frac{2}{\pi} \times E_{max} = 0.637E_{max}$$

Effective or rms value

$$E_{eff} = \frac{E_{max}}{\sqrt{2}} = \frac{E_{max}}{1.414} = 0.707E_{max} = 1.11E_{ave}$$

Maximum value

$$E_{max} = \sqrt{2}(E_{eff}) = 1.414E_{eff} = 1.57E_{ave}$$

Voltage in an ac circuit

$$E = IZ = \frac{P}{I \times PF}$$

Current in an ac circuit

$$I = \frac{E}{Z} = \frac{P}{E \times PF}$$

Power in AC Circuit

Apparent power: $P = EI$

True power: $P = EI \cos \theta = EI \times PF$

Power Factor

$$PF = \frac{P}{EI} = \cos \theta$$

$$\cos \theta = \frac{\text{true power}}{\text{apparent power}}$$

Transformers

Voltage relationship

$$\frac{E_p}{E_s} = \frac{N_p}{N_s} \text{ or } E_s = E_p \times \frac{N_s}{N_p}$$

Current relationship

$$\frac{I_p}{I_s} = \frac{N_s}{N_p}$$

Induced voltage

$$E_{eff} = 4.44 \times BAfN \times 10^{-8}$$

Turns ratio

$$\frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}}$$

Secondary current

$$I_s = I_p \times \frac{N_p}{N_s}$$

Secondary voltage

$$E_s = E_p \times \frac{N_s}{N_p}$$

Three-Phase Voltage and Current Relationships

With wye connected windings

$$E_{line} = \sqrt{3}(E_{coil}) = 1.732E_{coil}$$

$$I_{line} = I_{coil}$$

With delta connected windings

$$E_{line} = E_{coil}$$

$$I_{line} = 1.732I_{coil}$$

With wye or delta connected winding

$$P_{coil} = E_{coil}I_{coil}$$

$$P_t = 30P_{coil}$$

$$P_t = 1.732E_{line}I_{line}$$

(To convert to true power multiply by $\cos \theta$)

Resonance

At resonance

$$X_L = X_C$$

Resonant frequency

$$F_o = \frac{1}{2\pi\sqrt{LC}}$$

Series resonance

$$Z \text{ (at any frequency)} = R + j(X_L - X_C)$$

$$Z \text{ (at resonance)} = R$$

Parallel resonance

$$Z_{max} \text{ (at resonance)} = \frac{X_L X_C}{R} = \frac{X_L{}^2}{R} = QX_L = \frac{L}{CR}$$

Bandwidth

$$\Delta = \frac{F_o}{Q} = \frac{R}{2\pi L}$$

Tube Characteristics

Amplification factor

$$\mu = \frac{\Delta e_p}{\Delta e_g} (i_p \text{ constant})$$

$$\mu = g_m r_p$$

Ac plate resistance

$$r_p = \frac{\Delta e_p}{\Delta i_p} (e_g \text{ constant})$$

Grid-plate transconductance

$$g_m = \frac{\Delta i_p}{\Delta e_g} (e_p \text{ constant})$$

Decibels

NOTE: Wherever the expression "log" appears without a subscript specifying the base, the logarithmic base is understood to be 10.

Power ratio

$$dB = 10 \log \frac{P_2}{P_1}$$

Current and voltage ratio

$$dB = 20 \log \frac{I_2\sqrt{R_2}}{I_2\sqrt{R_1}}$$

$$dB = 20 \log \frac{E_2\sqrt{R_1}}{E_1\sqrt{R_2}}$$

NOTE: When R_1 and R_2 are equal they may be omitted from the formula. When reference level is one milliwatt

$$dBm = 10 \log \frac{P}{0.001} \text{ (when P is in watts)}$$

Synchronous Speed of Motor

$$\text{rpm} = \frac{120 \times \text{frequency}}{\text{number of poles}}$$

Comparison of Units in Electric and Magnetic Circuits

	Electric circuit	Magnetic circuit
Force	Volt, E, or emf	Gilberts, F, or mmf
Flow	Ampere, I	Flux, Φ, in maxwells
Opposition	Ohms, R	Reluctance, $\mathcal{R}$
Law	Ohm's law, $I = \frac{E}{R}$	Rowland's law, $\Phi = \frac{F}{\mathcal{R}}$
Intensity of force	Volts per cm of length.	$H = \frac{1.257IN}{L}$, gilberts per centimeter of length.
Density	Current density—for example, amperes per cm^2.	Flux density—for example, lines per cm^2 or gausses.

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NONRESIDENT CAREER COURSE

AVIATION ELECTRONICS TECHNICIAN 3 & 2, PART 2

NAVEDTRA 10317-F

Prepared by the Naval Education and Training Program Development Center, Pensacola, Florida

Your nonresident career course (NRCC) contains a set of assignments and perforated answer sheets. The Rate Training Manual, AVIATION ELECTRONICS TECHNICIAN 3&2, Part 2 NAVEDTRA 10317-F,is your textbook for the NRCC. If an errata sheet comes with the NRCC, make all indicated changes or corrections. Do not change anything else, but do make sure your ESO is aware of the errata in case it affects the grading of your answer sheets. Any errors that you find not already covered by the errata should be sent to the Naval Education and Training Program Development Center on the tear-out letter form at the back of this booklet. Your cooperation is appreciated.

HOW TO COMPLETE THIS COURSE SUCCESSFULLY

Study the textbook pages given at the beginning of each assignment before trying to answer the questions. Pay attention to tables and illustrations, as they contain a lot of information. Making your own drawings can help you understand the subject matter. Also, read the learning objectives that precede the sets of questions. The learning objectives and questions are based on the subject matter or study material in the textbook. The objectives tell you what you should be able to do by studying assigned textual material and answering the questions.

At this point you should be ready to answer the questions in the assignment. Read each question carefully. Be sure to select the BEST ANSWER from the subject matter in the textbook. You may discuss difficult points in the course with others. However, the answer you select must be your own. Remove a perforated answer sheet from the back of this text, write in the proper assignment number, and enter your answer for each question.

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Although you complete the course successfully, the Naval Education and Training Program Development Center will not issue you a letter of satisfactory completion. Your command will make an entry in your service record, giving you credit for your work.

WHEN YOUR COURSE IS ADMINISTERED BY THE NAVAL EDUCATION AND TRAINING PROGRAM DEVELOPMENT CENTER

After finishing an assignment, go on to the next. Retain each completed answer sheet until you finish all the assignments in a unit (or in the course if it is not divided into units). Using the envelopes provided, mail your completed answer sheets to the Naval Education and Training Program Development Center 32559 where they will be graded and the score recorded. Make sure all blanks at the top of each answer sheet are filled in. Unless you furnish all the information required, it will be impossible to give you credit for your work. The graded answer sheets will not be returned.

The Naval Education and Training Program Development Center will issue a letter of satisfactory completion to certify successful completion of the course (or a creditable unit of the course.) To receive a course-completion letter, follow the directions given on the course-completion form in the back of this NRCC.

You may keep the textbook and assignments for this course. Return them only in the event you disenroll from the course or otherwise fail to complete the course. Directions for returning the textbook and assignments are given on the book-return form in the back of this NRCC.

PREPARING FOR YOUR ADVANCEMENT EXAMINATION

Your examination for advancement is based on the Occupational Standards for your rating as found in the MANUAL OF NAVY ENLISTED MANPOWER AND PERSONNEL CLASSIFICATIONS AND OCCUPATIONAL STANDARDS (NAVPERS 18068). These Occupational Standards define the minimum tasks required of your rating. The sources of questions in your advancement examination are listed in the BIBLIOGRAPHY FOR ADVANCEMENT STUDY (NAVEDTRA 10052). For your convenience, the Occupational Standards and the sources of questions for your rating are combined in a single pamphlet for the series of examinations for each year. These OCCUPATIONAL STANDARDS AND BIBLIOGRAPHY SHEETS (called Bib Sheets), are available from your ESO. Since your textbook and NRCC are among the sources listed in the bibliography, be sure to study both as you take the course. The qualifications for your rating may have changed since your course and textbook were printed, so refer to the latest edition of the Bib Sheets.

NAVAL RESERVE RETIREMENT CREDIT

This course is evaluated at 6 Naval Reserve retirement points, which will be credited upon satisfactory completion of of the entire course. These points are creditable to personnel eligible to receive them under current directives governing retirement of Naval Reserve personnel.

COURSE OBJECTIVE

In completing this course you will, by answering questions, demonstrate knowledge needed to perform the duties of Aviation Electronics Technicians 3&2. Specifically, you should be able to:

Identify the components, purpose, use, and capabilities of the equipment associated with airborne communications, navigation, radar and IFF, and electronic countermeasures, as well as support equipment, reflectometry test sets, and magnetic recorders.

Recognize the safety precautions necessary in the use of these equipments; and the procedures necessary for their proper maintenance.

While working on this correspondence course, you may refer freely to the text. You may seek advice and instruction from others on problems arising in the course, but the solutions submitted must be the result of your own work and decisions. You are prohibited from referring to or copying the solutions of others, or giving complete solutions to anyone else taking the same course.

Naval courses may include a variety of questions -- multiple-choice, true-false, matching, etc. The questions are not grouped by type; regardless of type, they are presented in the same general sequence as the textbook material upon which they are based. This presentation is designed to preserve continuity of thought, permitting step-by-step development of ideas. Some courses use many types of questions, others only a few. The student can readily identify the type of each question (and the action required) through inspection of the samples given below.

MULTIPLE-CHOICE QUESTIONS

Each question contains several alternatives, one of which provides the best answer to the question. Select the best alternative, and blacken the appropriate box on the answer sheet.

SAMPLE

s-1. The first person to be appointed Secretary of Defense under the National Security Act of 1947 was
1. George Marshall
2. James Forrestal
3. Chester Nimitz
4. William Halsey

Indicate in this way on the answer sheet:

	1 T	2 F	3	4	
s-1	☐	■	☐	☐	___

TRUE-FALSE QUESTIONS

Mark each statement true or false as indicated below. If any part of the statement is false the statement is to be considered false. Make the decision, and blacken the appropriate box on the answer sheet.

SAMPLE

s-2. Any naval officer is authorized to correspond officially with any systems command of the Department of the Navy without his commanding officer's endorsement.

Indicate in this way on the answer sheet:

	1 T	2 F	3	4	
s-2	☐	■	☐	☐	___

MATCHING QUESTIONS

Each set of questions consists of two columns, each listing words, phrases or sentences. The task is to select the item in column B which is the best match for the item in column A that is being considered. Items in column B may be used once, more than once, or not at all. Specific instructions are given with each set of questions. Select the numbers identifying the answers and blacken the appropriate boxes on the answer sheet.

SAMPLE

In questions s-3 through s-6, match the name of the shipboard officer in column A by selecting from column B the name of the department in which the officer functions.

A	B
s-3. Damage Control Assistant	1. Operations Department
s-4. CIC Officer	2. Engineering Department
s-5. Disbursing Officer	3. Supply Department
s-6. Communications Officer	

Indicate in this way on the answer sheet:

	1 T	2 F	3	4	
s-3	☐	■	☐	☐	___
s-4	■	☐	☐	☐	___
s-5	☐	☐	■	☐	___
s-6	■	☐	☐	☐	___

Assignment 1

Airborne Communications Equipment

Textbook Assignment: pages 1-1 through 1-43

Learning Objective: State the purpose and capabilities of a general-purpose receiver; identify various components, and state their function.

1-1. In airborne electronics equipment, why is subassembly and modular construction used?

1. It simplifies maintenance and repair
2. It makes instruction easier
3. It is cost effective
4. It reduces vibration effects of normal flight

1-2. Which of the following types of signals can be processed by a typical general purpose receiver?

1. AM, FM, and CW
2. AM, FM, and FSK
3. AM, CW, and FSK
4. FM, CW, and FSK

1-3. What information is contained in a maintenance instruction manual for a particular general purpose receiver?

1. The theory of operation only
2. The theory of operation and specifications only
3. The theory of operation, tests, alignment procedures, specifications, and test equipment required
4. Overhaul instructions

1-4. Which of the following benefits are obtained from using double conversion in a receiver?

1. High gain and sensitivity
2. High gain and selectivity
3. High sensitivity and selectivity
4. Low gain and sensitivity

1-5. In a general-purpose receiver, the BFO enables the receiver to process what signals?

1. FM signals
2. AM signals
3. FSK signals
4. CW signals

IN ANSWERING QUESTIONS 1-6 and 1-7, REFER TO FIGURE 1-2 OF THE TEXT.

1-6. What is the function of Q703?

1. To produce a fixed IF
2. To produce a variable IF
3. To amplify the incoming RF
4. To limit the incoming RF

1-7. What is the purpose of the spectrum generator (Q750 & Q751) in the receiver?

1. To calibrate the frequency indicator dial
2. To enable processing of CW signals
3. To produce a variable IF
4. To produce a fixed IF

Learning Objective: State the purpose and capabilities of an HF transceiver; identify and state the function of various components of the AN/ARC-94.

1-8. What is the frequency range of the AN/ARC-94 HF transceiver?

1. 2.0 to 29.999 kHz
2. 2.0 to 29.999 MHz
3. 2.0 to 29.999 GHz
4. 29 to 55.999 GHz

QUESTION 1-9 IS TO BE JUDGED TRUE OR FALSE.

1-9. An AN/ARC-94 HF system contains a transceiver, control unit, mounting assembly, headset, microphone, key, antenna coupler, and an antenna.

1. True
2. False

1-10. How many different operating frequencies are available with the AN/ARC-94 HF transceiver?

1. 28,000
2. 30,000
3. 32,000
4. 34,000

1-11. On a simplified block diagram of the AN/ARC-94 transceiver, which of the following nomenclature would designate a component located on a submodule?

1. A1R1
2. A12A2R1
3. A12A2
4. A12R1

1-12. In the transmit function of the AN/ARC-94, which section provides coupling and amplification for the voice intelligence to be transmitted?

1. RF translator
2. IF translator
3. AF input
4. Power amplifier

1-13. In which of the following modes of the AN/ARC-94 mode selector switch is the upper sideband mode always used?

1. DATA and CW
2. DATA and AM
3. DATA, AM, and CW
4. CW and AM

1-14. Which of the following circuits of the RT-648/ARC-94 actuate(s) the stages that must operate in order to transmit?

1. The translator circuit
2. The sidetone circuits
3. The power amplifier circuits
4. The keying circuits

IN ANSWERING QUESTION 1-15, REFER TO FIGURE 1-5 OF THE TEXT.

1-15. The sidetone signal for monitoring transmitted audio comes from which stage?

1. A3Q2
2. A9CR4
3. A3Q1
4. A9Q2

1-16. Which of the following devices prevents the RT-648/ARC-94 keying circuits from energizing the transmitter during the tuning cycle of the equipment?

1. The recycle relay
2. The mode selector switch
3. The IF translator
4. The RF translator

Learning Objective: State the operating frequency ranges of a VHF transceiver.

1-17. What is the normal frequency range of a VHF transceiver?

1. 2.0 to 29.999 kHz
2. 2.0 to 29.999 MHz
3. 116 to 149.95 MHz
4. 116 to 151.95 MHz

1-18. What is the operating frequency of a VHF transceiver's receiver, when it is used in conjunction with VOR?

1. 2.0 to 29.99 kHz
2. 108 to 151.95 MHz
3. 116 to 149.95 MHz
4. 116 to 151.95 MHz

Learning Objective: State the purpose and capabilities of UHF transceivers; identify and state the function of various components of the AN/ARC-159.

1-19. The purpose of Radio Set AN/ARC-88 is to provide which of the following links between aircraft, shore, and ships?

1. UHF, amplitude-modulated
2. UHF, frequency-modulated
3. UHF, CW-modulated
4. SSB

1-20. What is the operating frequency range of the RT-649/ARC-88?

1. 2.0 to 29.99 kHz
2. 108 to 151.95 MHz
3. 116 to 151.95 MHz
4. 225 to 399.9 MHz

1-21. At what internal temperature of the RT-649/ARC-88 will the HD-513/ARC external blower motor turn on?

1. 35°C
2. 20°C
3. 75°F
4. 65°F

1-22. The purpose of the AN/ARC-159 UHF transceiver is to provide which of the following communications between aircraft, shore, and ships?

1. Two-way frequency-modulated
2. Two-way CW
3. Two-way amplitude-modulated
4. SSB

1-23. What is the operating frequency range of the AN/ARC-159 transceiver?

1. 2.0 to 29.99 kHz
2. 108 to 151.95 kHz
3. 116 to 151.95 MHz
4. 225 to 399.975 MHz

1-24. How many receivers are employed in the AN/ARC-159?

1. One
2. Two
3. Three
4. Four

1-25. What is the UHF International Distress Frequency?

1. 225 MHz
2. 243 MHz
3. 249 MHz
4. 399.975 MHz

1-26. How many receivers of the AN/ARC-159 can be monitored simultaneously?

1. One
2. Two
3. Three
4. Four

1-27. How many operating frequencies are available with the AN/ARC-159 UHF transceiver?

1. 7,000
2. 7,500
3. 8,000
4. 8,500

1-28. The AN/ARC-159 transceiver can be manually tuned from 225 MHz to 399.975 MHz in which of the following increments?

1. 5 kHz
2. 25 kHz
3. 50 kHz
4. 5 MHz

IN ANSWERING QUESTIONS 1-29 AND 1-30, REFER TO FIGURE 1-11 AND TABLE 1-2 OF THE TEXT.

1-29. Which, if any, of the following would be the output frequency of the AN/ARC-159 transmitter if the mode selector switch (item #9) were in the GUARD position?

1. 225 MHz
2. 243 MHz
3. 249 MHz
4. The frequency would be unknown

1-30. Which of the following controls will set the 100-MHz and 10-MHz frequency increments in the manual mode of operation of the AN/ARC-159?

1. Item #3
2. Item #4
3. Item #5
4. Item #6

1-31. How many preset frequency channels are available with the AN/ARC-159?

1. 5
2. 10
3. 15
4. 20

IN ANSWERING QUESTIONS 1-32 THROUGH 1-47, REFER TO FIGURES 1-13 THROUGH 1-21 OF THE TEXT.

1-32. What section of the AN/ARC-159 transceiver provides mixer injection frequencies and tuning voltages needed by the RF translator/modulator 1A2?

1. IF/audio amplifier
2. Frequency synthesizer
3. Guard receiver
4. Power amplifier/power supply

1-33. What is the operating frequency range of the VCO 1A1A1Q1?

1. 2.0025 to 12.0 MHz
2. 25.0 to 34.9975 MHz
3. 125.0 to 174.9875 MHz
4. 250.0 to 349.975 MHz

1-34. What determines the division ratio of the variable divider 1A1A4?

1. The output of loop mixer 1A1A3
2. The output of VCO 1A1A1Q1
3. The output of frequency standard 1A1A2Y1
4. The frequency setting of the control section 1A6

1-35. Which, if any, of the following is the purpose of the Frequency Phase Discriminator 1A1A4U14?

1. To compare the output frequency of the VCO with a known frequency standard
2. To compare the output frequency of the loop mixer with a known frequency standard
3. To compare the signal amplitude of the frequency standard with the IF signal amplitude
4. None of the above

1-36. What section of the AN/ARC-159 transceiver supplies the tuning voltage for the RF translator's electronic filters?

1. Power Amplifier 1A5
2. IF/Audio Amplifier 1A3
3. Frequency Synthesizer 1A1
4. Guard receiver 1A4

1-37. What is the output of the RF/translator (1A2) modulator Q202?

1. A 50-MHz CW signal
2. A 50-MHz amplitude-modulated signal
3. A 50-MHz frequency-modulated signal
4. An audio signal

1-38. What is the purpose of the ALC control voltage applied to RF translator 1A2?

1. To increase transmitter power output
2. To fine tune the transmitter frequency
3. To fine tune the receiver frequency
4. To reduce transmitter power output in the event of a bad VSWR

1-39. What is the output of Q6 of the RF translator 1A2?

1. 50-MHz CW signal
2. 50-MHz AM transmitted signal
3. 50-MHz AM received signal
4. 50-MHz FM signal

1-40. In which of the following modes of operation of the AN/ARC-159 is the IF/Audio Amplifier (1A3) 500-kHz bandpass filter NOT used?

1. Main receiver
2. Guard receiver
3. Both receivers
4. ADF

1-41. What is the purpose of the IF/Audio Amplifier 1A3 sidetone in signal?

1. To allow operators to monitor their own transmissions
2. To isolate the squelch circuits during guard receiver time
3. To allow the guard receiver to be passed by the isolation network
4. To eliminate the AVC signal

1-42. What is the frequency range of the AN/ARC-159 guard receiver 1A4?

1. 225 to 399.9 MHz
2. Fixed tuned at 243 MHz
3. 2.0 to 29.99 kHz
4. 108 to 151.95 kHz

1-43. What is the 1st IF frequency of the AN/ARC-159 guard receiver?

1. 25.5 MHz
2. 217.5 MHz
3. 243.0 MHz
4. 300.0 MHz

1-44. What is the 2nd IF frequency of the AN/ARC-159 guard receiver?

1. 217.5 MHz
2. 75.0 MHz
3. 25.5 MHz
4. 2.5 MHz

1-45. What is the carrier output power of the AN/ARC-159 transmitter?

1. 100 watts
2. 50 watts
3. 10 watts
4. 5 watts

1-46. What is the function of U3A (figure 1-19) of the power amplifier/power supply module 1A5?

1. To amplify the forward output voltage
2. To continuously monitor the ratio of forward and reflected output voltages
3. To detect the output audio signal
4. To amplify the reflected output voltage

1-47. At what temperature will the thermal switch (S1) in series with the PTT key line of the 1A5 module (figure 1-19) open?

1. 100°F
2. 150°F
3. 200°F
4. 212°F

Learning Objective: State the purpose and operation of the A1C-14A intercommunication system; identify various controls and components, and state their functions.

1-48. An aircraft's intercommunications system provides which of the following functions?

1. Permits crewmembers to speak to each other
2. Permits crewmembers to receive and transmit messages over the aircraft's communications equipment
3. Permits the recording of all in-flight communications
4. All of the above

1-49. In normal operation, what is the purpose of the isolation amplifier (part of C2645D/A1C-14A)?

1. To amplify and isolate all transmitted audio from a particular crew station
2. To amplify and isolate all incoming audio to a particular crew station
3. To isolate intercom audio from communication transmitters
4. To isolate incoming communication audio from transmitted intercommunication audio

1-50. In normal operation, what is the purpose of the interphone amplifier (part of C2645D/A1C-14A)?

1. To amplify and isolate all transmitted audio from a particular crew station
2. To amplify and isolate all incoming audio to a particular crew station
3. To isolate intercom audio from communication transmitters
4. To isolate incoming communication audio from transmitted intercommunication audio

IN ANSWERING QUESTIONS 1-51 AND 1-52, REFER TO FIGURE 1-23 OF THE TEXT.

1-51. Which of the following controls of the C2645D/A1C-14A adjusts the audio level of the isolation amplifier?

1. Item #4
2. Item #3
3. Item #2
4. Item #1

1-52. Which of the following controls of the C2645D/AlC-14A control the operation of "voice keying" of the system?

1. Items 1 and 2
2. Items 2 and 3
3. Items 3 and 4
4. Items 4 and 5

IN ANSWERING QUESTIONS 1-53 AND 1-54, REFER TO FIGURE 1-26 OF THE TEXT.

1-53. What is the purpose of the C4951/AlC-14A?

1. It is used in conjunction with the C2645D/AlC-14A to control the operator's UHF microphone and incoming communications audio
2. It is used in conjunction with the C2645D/AlC-14A to control the operator's ICS microphone and incoming audio
3. It is used to key the ICS system
4. It is used to key the various communications transmitters

1-54. If the ALL/MIXED/SEL'D switch (Item #3) is in the MIXED position, to which, if any, of the following stations (PLT, CPLT, CICO, ACO, RO) can the operator listen?

1. The station with switches (Item #1) in the "up" position
2. All stations simultaneously
3. The stations with switches (Item #1) in the "down" position
4. No stations

1-55. The C4949/AlC-14A is used in conjunction with (a) what equipment for (b) what purpose?

1. (a) C-2645D/AlC-14A
   (b) To control the communications receiver audio and transmitter microphone
2. (a) C-4951/AlC-14A
   (b) To control the communications receiver audio and transmitter microphone
3. (a) C-2645D/AlC-14A
   (b) To control ICS audio
4. (a) C-4951/AlC-14A
   (b) To control ICS audio

1-56. Which of the following antennas produces high gain and excellent directivity?

1. Dipole
2. Ground plane
3. Parabolic
4. Ram's horn

Assignment 2

Airborne Navigation Equipment

Textbook Assignment: pages 2-1 through 2-81

Learning Objective: State the purpose and capabilities of an Automatic Direction Finder (ADF) receiver system; identify various components and state their function.

2-1. An ADF indicator pointer (needle) will indicate which of the following information?

1. Magnetic bearing to a station
2. Relative bearing to a station
3. Magnetic bearing from a station
4. Relative bearing from a station

2-2. In the manual mode of operation of the loop antenna, when will the indicator needle point toward the received station?

1. When the received signal is maximum as heard in the headphones
2. When the received signal causes the pointer to move
3. When the received signal is minimum as heard in the headphones
4. When the indicator pointer stops

2-3. What type of antenna is the "sense antenna" of an ADF system?

1. Helix
2. Dipole
3. Cosecant square
4. Monopole

2-4. Why does an ADF system require both a loop and a sense antenna?

1. To prevent the system from indicating a 90° error
2. To prevent the system from indicating a 120° error
3. To prevent the system from indicating a 180° error
4. To prevent the system from indicating a 270° error

2-5. Of the following types of loop antennas, which does not require a sense antenna?

1. Rhombic
2. Monopole
3. Dipole
4. Helix

2-6. What is the frequency range of the ARD-13 ADF?

1. 90 kHz to 1800 kHz
2. 1800 kHz to 2500 kHz
3. 2500 kHz to 90 MHz
4. 90 MHz to 1800 MHz

2-7. Which of the following signals can be received by the ARD-13 ADF?

1. AM and FM
2. CW and FM
3. AM and CW

IN ANSWERING QUESTIONS 2-8 THROUGH 2-11, REFER TO FIGURE 2-8 OF THE TEXT.

2-8. In the ANT mode of operation, what is/are the input signal(s) to the RF amplifier?

1. Loop antenna signal only
2. Sense antenna signal only
3. Loop and sense antenna signals

2-9. Which of the following output(s) is/are used as the AVC voltage for the RF and IF amplifiers?

1. Detector only
2. 400 Hz oscillator only
3. Detector and 400 Hz oscillator
4. Balanced modulator

2-10. What is the input signal to the RF amplifier in the "loop" mode of operation?

1. Output of the sense antenna coupler
2. Output of the IF amplifier
3. Output of the audio amplifier
4. Output of the balanced modulator

2-11. What is the output of the discriminator when the 47 Hz variable signal and the 47 Hz oscillator signal are in phase?

1. Positive ac voltage
2. Positive dc voltage
3. Negative ac voltage
4. Negative dc voltage

2-12. When is "night effect" most noticeable in an ADF system?

1. One hour around midnight
2. One hour around noon
3. One hour around sunset only
4. One hour around sunrise and sunset

2-13. What is the purpose of calibrating a newly installed ADF loop antenna on an aircraft?

1. To eliminate "night effect"
2. To eliminate electrical disturbances
3. To eliminate quadrantal error
4. To eliminate precipitation static

2-14. What is the operating frequency range of the AS-909/ARA-48 ADF antenna?

1. 90 kHz to 1800 kHz
2. 225 kHz to 400 kHz
3. 90 MHz to 1800 MHz
4. 225 MHz to 400 MHz

2-15. To which of the following effects are UHF ADF antennas most vulnerable?

1. Quadrantal error and electrical disturbance
2. Electrical disturbance and night effect
3. Quadrantal error and night effect
4. Night effect and skin effect

Learning Objective: State the purpose and capabilities of a VOR radio navigation system; identify various components and state their function.

2-16. What is the purpose of a VOR navigation system?

1. To let a pilot know when the aircraft is over a given station
2. To give a pilot altitude information
3. To allow a pilot to guide an aircraft over long distances
4. To give a pilot bearing and distance to a given station

2-17. What is the frequency band of a VOR transmitter?

1. 9.96 kHz to 117.9 MHz
2. 112.00 MHz to 117.9 MHz
3. 121.00 MHz to 126.9 MHz
4. 117.90 MHz to 225.0 MHz

2-18. What is the modulation frequency induced in the airborne VOR receiver by the VOR transmitting station?

1. 30 Hz
2. 30 kHz
3. 30 MHz
4. 30 GHz

2-19. What is the frequency range of a VOR airborne receiver?

1. 9.96 kHz to 117.9 kHz
2. 112.00 MHz to 117.9 MHz
3. 108.00 MHz to 135.9 MHz
4. 225.00 MHz to 399.9 MHz

2-20. What is the frequency band of VOR weather information reception?

1. 108 MHz to 110.9 MHz
2. 111 MHz to 111.9 MHz
3. 112 MHz to 117.9 MHz
4. 118 MHz to 121.9 MHz

IN ANSWERING QUESTION 2-21, REFER TO FIGURE 2-17 OF THE TEXT.

2-21. For what purpose is the ID-249 Course Set knob used?

1. To center the vertical bar in order to obtain the correct bearing information to a station
2. To center the heading marker pointer to indicate true north
3. To center the vertical bar to indicate true north
4. To turn on the marker beacon light

Learning Objective: State the purpose and capabilities of an ILS system; identify various signals and state their function.

2-22. What is the purpose of the ILS localizer signals?

1. To give altitude information
2. To give bearing information
3. To give runway center-line information
4. To give "over station" information

IN ANSWERING QUESTION 2-23, REFER TO FIGURE 2-17 OF THE TEXT.

2-23. Which of the following components of the ID-249 is used for indicating glidepath information?

1. Marker beacon light
2. Course Select window
3. Vertical bar
4. Horizontal bar

2-24. What is the frequency of the ILS marker beacon transmitter?

1. 75.0 MHz
2. 108.0 MHz
3. 117.9 MHz
4. 135.9 MHz

Learning Objective: State the purpose and capabilities of a TACAN system; identify various components and state their function.

2-25. What information is derived from a TACAN system?

1. Bearing to a station only
2. Bearing from a station only
3. Bearing and distance to or from a station

2-26. How often does a TACAN station identify itself?

1. Every 37.5 seconds
2. Every 60.5 seconds
3. Every 70.5 seconds
4. Every 90.5 seconds

2-27. Within the 300-nautical-mile maximum, the range at which a TACAN transceiver can process signals is determined by which of the following factors?

1. Altitude of the aircraft
2. DME power of the aircraft's transceiver
3. DME power of the ground station
4. All of the above

2-28. What is the frequency of the coarse TACAN station bearing signal pattern?

1. 5 Hz
2. 10 Hz
3. 15 Hz
4. 25 Hz

2-29. What is the frequency of the fine TACAN bearing signal pattern?

1. 15 Hz
2. 135 Hz
3. 15 kHz
4. 135 kHz

2-30. What is the bearing accuracy of an aircraft TACAN system?

1. ±1 degree
2. ±2 degrees
3. ±3 degrees
4. ±5 degrees

2-31. After the loss of signals, an aircraft TACAN transceiver memory circuit will hold a DME reading what maximum number of seconds before it goes into the search function?

1. 10 seconds
2. 20 seconds
3. 30 seconds
4. 60 seconds

2-32. What is the maximum allowable DME distance error in an aircraft TACAN transceiver?

1. ±600 feet
2. ±675 feet
3. ±720 feet
4. ±800 feet

2-33. What is the frequency band of operation of a TACAN ground station?

1. 15 Hz to 135 Hz
2. 962 Hz to 1213 Hz
3. 15 MHz to 135 MHz
4. 962 MHz to 1213 MHz

2-34. How many preset channels does an airborne TACAN transceiver have?

1. 26
2. 126
3. 226
4. 326

2-35. In the airborne TACAN transceiver, how far apart are the transmitter and receiver frequencies?

1. 63 MHz
2. 100 MHz
3. 126 MHz
4. 200 MHz

2-36. What information can be obtained from an airborne TACAN system when operating in the air-to-air mode with another aircraft?

1. Bearing and DME
2. Bearing only
3. DME only
4. Identification tone only

IN ANSWERING QUESTION 2-37, REFER TO FIGURE 2-30 OF THE TEXT.

2-37. Which module of the TACAN receiver-transmitter separates the received bearing and DME signals?

1. Range decoder module
2. RF module
3. Range A module
4. Antenna selector module

2-38. How long after reception of an air-to-air interrogation signal will an aircraft TACAN transceiver generate a reply pulse?

1. 10 microseconds
2. 20 microseconds
3. 30 microseconds
4. 50 microseconds

2-39. Which of the following TACAN indicators is/are replaced by an HSI indicator?

1. Course indicator
2. Course deviation indicator
3. DME indicator
4. All of the above

Learning Objective: State the purpose and capabilities of an airborne electronic altimeter system.

2-40. What type of altitude information is displayed by an airborne electronic altimeter system?

1. Height above sea level
2. Height above the terrain below the aircraft
3. Height above the terrain in front of the aircraft

2-41. What does an aircraft electronic altimeter measure in order to indicate altitude?

1. Received signal power
2. Transmitted signal power
3. The time from the moment the transmitter fires until the signal returns from the terrain below
4. The time between received signals

2-42. What is the maximum altitude readout of an APN-194 electronic altimeter?

1. 5,000 feet
2. 10,000 feet
3. 15,000 feet
4. 20,000 feet

2-43. What is the pulse repetition frequency on the APN-194 electronic altimeter transmitter?

1. 7,000 pps
2. 7,500 pps
3. 8,000 pps
4. 8,500 pps

2-44. In the self-test mode of the APN-194, what should the altimeter reading be?

1. 100 feet
2. 200 feet
3. 500 feet
4. 700 feet

2-45. After it stops receiving a signal, the APN-194 will indicate an altitude reading for what maximum time?

1. 0.2 second
2. 1.2 seconds
3. 2.0 seconds
4. 5.0 seconds

2-46. What is the typical operating frequency range of electronic (radar) altimeters?

1. 4,250 to 4,350 MHz
2. 4,250 to 4,350 kHz
3. 8,500 Hz
4. 9,000 Hz

IN ANSWERING QUESTIONS 2-47 AND 2-48, REFER TO FIGURE 2-42 OF THE TEXT.

2-47. What indicates that the altimeter system is "on"?

1. The self-test lamp blinks
2. The low-altitude warning lamp comes on
3. The OFF flag disappears
4. The height indicating needle is behind the mask

2-48. In the self-test mode, the low-altitude warning lamp will come on under which of the following conditions?

1. When the control knob is pushed
2. When the control knob is fully clockwise
3. When the low-altitude-limit index is adjusted above 100 feet
4. When the low-altitude-limit index is adjusted below 100 feet

Learning Objective: State the purpose and capabilities of a loran system.

2-49. What is the purpose of an airborne loran system?

1. Long range radio navigation
2. Long range radar navigation
3. Short range radio navigation
4. Short range radar navigation

2-50. What is the minimum number of ground station signals required to obtain a loran line of position (fix)?

1. 1
2. 2
3. 3
4. 4

2-51. What is the transmitting frequency of loran C ground stations?

1. 25 kHz
2. 50 kHz
3. 75 kHz
4. 100 kHz

2-52. How many lines of position (LOPs) are required to obtain a loran C fix?

1. 1
2. 2
3. 3
4. 4

2-53. What is the timing standard of the DLR/70 loran receiver?

1. 80 kHz crystal controlled oscillator
2. 100 kHz crystal controlled oscillator
3. 80 kHz multivibrator
4. 100 kHz multivibrator

2-54. What is the voltage potential between the cathode and plate of the DLI/70 indicator CRT?

1. 1,300 volts dc
2. 2,600 volts dc
3. 1,300 volts ac
4. 2,600 volts ac

Learning Objective: Describe the purpose and the operating features of the Omega navigation system.

2-55. What is the accuracy of Omega lines of position?

1. Within 12 miles
2. Within 8 miles
3. Within 4 miles
4. Within 1 mile

2-56. In obtaining lines of position, the Omega navigation system differs from the loran system in that the Omega system uses the measurement of what relationship between station signals?

1. Time
2. Phase
3. Amplitude
4. Frequency

2-57. The lines of any ____(a)____ (two, three) Omega stations produce a family of ____(b)____ (hyperbolas, parabolas) called isophase contours.

1. (a) two (b) hyperbolas
2. (a) two (b) parabolas
3. (a) three (b) hyperbolas
4. (a) three (b) parabolas

2-58. How are lane widths determined in an Omega navigation system?

1. By the pulse width of transmission signals
2. By the time between bursts of transmission signals
3. By the frequency of transmission signals
4. All lane widths are eight nautical miles wide

2-59. In the Omega system the presently employed frequency of ____(a)____ (10.2 kHz, 11.33 kHz) has a half wavelength of ____(b)____ (seven, six) nautical miles along the baseline.

1. (a) 10.2 kHz (b) seven
2. (a) 11.33 kHz (b) seven
3. (a) 10.2 kHz (b) six
4. (a) 11.33 kHz (b) six

2-60. The lane in which a receiving station is located can be determined by which of the following methods?

1. Counters
2. Graphic readout
3. Difference ratio in transmission frequencies with dead reckoning
4. Each of the above

2-61. The Omega stations broadcast a pattern of interrupted transmissions repeating at a time interval of how many seconds?

1. 7 seconds
2. 8 seconds
3. 9 seconds
4. 10 seconds

QUESTION 2-62 IS TO BE JUDGED TRUE OR FALSE.

2-62. Omega time is identical to Greenwich Mean Time.

1. True
2. False

2-63. The velocity of Omega phase propagation is determined by which of the following factors?

1. Surface conductivity
2. The earth's magnetic field
3. Ionospheric height
4. All of the above

2-64. How does the Omega navigation system compensate for diurnal shifts of the ionosphere?

1. By adjusting the power of transmission
2. By adjusting the frequency of transmission
3. By using published skywave correction factors

IN ANSWERING QUESTIONS 2-65 THROUGH 2-67, REFER TO FIGURE 2-62 AND TABLE 2-5 OF THE TEXT.

2-65. On the Omega computer control indicator, under what condition will the RATE AID FAIL (#5) indicator illuminate?

1. When the difference between true airspeed and groundspeed exceeds 200 knots
2. When the difference between true airspeed and groundspeed is less than 200 knots
3. When the true airspeed exceeds 200 knots
4. When the groundspeed exceeds 200 knots

2-66. On the Omega computer control indicator, when will the SYSTEM MALF indicator (#4) illuminate?

1. During any normal operation
2. During any self-test operation
3. During normal operation when airspeed exceeds 200 knots
4. During self-test operation when a malfunction is detected

2-67. The EP indicator (#10) on the Omega computer control indicator informs the operator of which of the following conditions?

1. That emergency power is being used by the system
2. That the E Omega station signals are being used by the system
3. That a new aircraft position has not been entered since system turn-on
4. That the E and P Omega station signals are being used by the system

Assignment 3

Radar and IFF

Textbook Assignment: pages 3-1 through 3-30

Learning Objective: Describe the general circuitry and operation of a typical pulse radar set.

3-1. What is the basic function of a synchronizer in a typical radar set?

1. Timing
2. IFF determination
3. Interrogation
4. Amplification

3-2. What is the output of the synchronizer frequency converter?

1. 400-Hz trigger pulses
2. 1600-Hz trigger pulses
3. 400-Hz and 1600-Hz sawtooth waves
4. 400-Hz and 1600-Hz square waves

IN ANSWERING QUESTION 3-3, REFER TO FIGURE 3-3 OF THE TEXT.

3-3. What is the purpose of the output from the line driver following Z5?

1. Indicator trigger
2. Premaster trigger
3. IFF trigger
4. Transmitter trigger

3-4. In radars which use a master oscillator for basic timing, which of the following types of oscillator is used?

1. Sine-wave oscillator
2. Astable multivibrator
3. Blocking oscillator
4. Each of the above

3-5. A PPI display shows which of the following information, relative to your own aircraft?

1. Landform configurations
2. Range of target
3. Azimuth of the target
4. All of the above

3-6. What effect does the ion trap have on the negative ions in an electromagnetic CRT?

1. It collects them on the phosphorescent screen
2. It changes their direction of motion
3. It deflects them to the cathode
4. It collects them on the anode

IN ANSWERING QUESTIONS 3-7 THROUGH 3-9, REFER TO FIGURE 3-8 OF THE TEXT.

3-7. From what component does the timing trigger come?

1. Sweep generator
2. Synchronizer
3. Antenna
4. Video amplifier

3-8. What is the static condition of Q1 with no input signal?

1. Conducting
2. Cutoff
3. Reversed biased

3-9. What condition must be present to change the static conduction state of Q2?

1. Negative signal to the base
2. Positive signal to the emitter
3. Positive signal to the base of Q1
4. Positive signal from collector of Q1

3-10. What shape wave comes from the sweep generator?

1. Trapezoidal
2. Square
3. Sine
4. Sawtooth

IN ANSWERING QUESTION 3-11, REFER TO FIGURE 3-9A.

3-11. What is the rate of charge dependent upon for C1?

1. R1 x C1
2. R1 + R2 x C1
3. R2 x C1
4. R2 x R1

3-12. What is the normal amount of current required by deflection circuits for maximum deflection?

1. 5 to 10 amps
2. 5 to 50 mA
3. 50 to 100 mA
4. 100 to 150 mA

3-13. Electromechanical repeaters and the mechanical azimuth sweep are both used in a PPI for what purpose?

1. Rotation of the antenna
2. Alignment of the antenna
3. Synchronization
4. Deflection

3-14. In the electrical azimuth sweep circuitry, the sweep clamper circuit performs which of the following functions?

1. Keeps the reference level constant
2. Causes each sweep to start at the same point on the CRT
3. Both 1 and 2 above

IN ANSWERING QUESTIONS 3-15 AND 3-16, REFER TO FIGURE 3-12.

3-15. What is the static state of Q1?

1. Conducting
2. Cutoff
3. Reversed biased

3-16. Q4 serves as what component?

1. An oscillator
2. An emitter follower
3. An amplifier
4. A timer

IN ANSWERING QUESTION 3-17, REFER TO FIGURE 3-13 OF THE TEXT.

3-17. What is the purpose of the video limiter?

1. To steady positive output
2. To produce negative pulses
3. To prevent blooming
4. To increase range mark intensity

3-18. Which of the following capabilities is/are required of a typical radar receiver?

1. High gain
2. Low noise
3. Both 1 and 2 above
4. High intensity

IN ANSWERING QUESTION 3-19, REFER TO FIGURE 3-14A OF THE TEXT.

3-19. What is the normal output of the hybrid junction?

1. Two inputs - one output
2. Two inputs - two outputs
3. One input - one output
4. One input - two outputs

3-20. What is the purpose of the coaxial probes in the hybrid junction microwave mixer?

1. To couple the input
2. To couple the output
3. For impedance matching
4. To reduce noise

3-21. A varactor diode is useful for tuning oscillator tank circuits over a wide frequency range because it has which of the following qualities?

1. Variable junction capacitance
2. Variable junction inductance
3. Extreme sensitivity
4. Constant reactance for 360° input signal

IN ANSWERING QUESTIONS 3-22 AND 3-23, REFER TO FIGURE 3-17 OF THE TEXT.

3-22. What is the purpose of C9?

1. Bypass capacitor
2. Feedback capacitor
3. Tank circuit with L4
4. Biasing capacitor

3-23. What type of oscillator is formed by Q1, CR1, and L4?

1. Hartley
2. Blocking
3. Colpitts
4. Pierce

IN ANSWERING QUESTIONS 3-24 AND 3-25, REFER TO FIGURE 3-19 OF THE TEXT.

3-24. What is the purpose of R1 and R2?

1. To develop input signals
2. To make bias adjustments
3. To act as load resistors
4. To act as gain resistors

3-25. T1 adjusts for which of the following quantities?

1. Bandwidth
2. Gain figure
3. Both 1 and 2
4. Balance

3-26. What is the purpose of the operator's sensitivity time control adjustment on the control panel of the typical radar set?

1. To vary the timing of the azimuth sweep
2. To change variable ranges by hand
3. To prevent saturation of the display indicator
4. To set range marks to desired distance

IN ANSWERING QUESTIONS 3-27 AND 3-28, REFER TO FIGURE 3-21 OF THE TEXT.

3-27. What is the approximate gain of amplifier A?

1. 1
2. 2
3. 3
4. 4

3-28. T1 and C8 form a tuned tank. To which, if any, of the following frequencies are they tuned?

1. RF frequency
2. IF frequency
3. Input frequency
4. None of the above

3-29. What is the purpose of the AFC circuitry in a typical radar receiver?

1. To tune the local oscillator
2. To establish the IF frequency
3. To set the gain of the IF stages

3-30. AFC circuits use which of the following modes of operation to tune the local oscillator to the correct frequency?

1. Search
2. Acquisition
3. Loop control
4. All of the above

3-31. What is the normal bandpass of the typical radar receiver?

1. 300 kHz
2. 500 kHz
3. 10 MHz
4. 22 MHz

3-32. The output voltage of AR2 (fig. 3-24) is a sawtooth. This has resulted from the output of which component?

1. AR2 (fig. 3-23)
2. Q22 (fig. 3-23)
3. CR1 (fig. 3-24)
4. AR1 (fig. 3-24)

IN ANSWERING QUESTIONS 3-33 AND 3-34, REFER TO FIGURE 3-25 OF THE TEXT.

3-33. What supplies the reference signal for the discriminator?

1. T1
2. Q3
3. Q4
4. Q6

3-34. What is the output signal from Q11?

1. Amplified video target signal
2. IF output signal
3. Video error signal
4. Wide-band video signal

3-35. The slow-loop and fast-loop modes of operation combine to put the desired oscillator frequency to which of the following operating frequency ranges?

1. ±10 MHz of the IF
2. ±5 MHZ of the IF
3. IF center frequency

IN ANSWERING QUESTION 3-36, REFER TO FIGURE 3-24 OF THE TEXT.

3-36. Which, if any, of the following factors determines that the length of time sample gates Q1 and Q2 will remain open?

1. The target distance
2. The PRF of the radar
3. The video error signal
4. None of the above

IN ANSWERING QUESTION 3-37, REFER TO FIGURE 3-26 OF THE TEXT.

3-37. What is the primary purpose of L3?

1. Act as a parallel filter
2. Act as a series filter
3. It is part of the tank circuit
4. To produce impedance matching

Learning Objective: Describe the general characteristics and functions of a typical IFF/SIF System.

3-38. In a typical IFF system, which unit is the responder station?

1. The radar unit
2. The synchronizer
3. The transponder unit
4. The interrogator

3-39. Of the five modes of IFF operation, which of the following is used to give altitude to an ATCRBS?

1. Mode 2
2. Mode 3/A
3. Mode C
4. Mode 4

3-40. Of the following modes of IFF operation, which is a military encrypted mode?

1. Mode 1
2. Mode 2
3. Mode C
4. Mode 4

3-41. The SLS pulse performs which of the following function(s)?

1. Prevents jamming
2. Suppresses receiver during TACAN operation
3. Suppresses receiver during L Band equipment operation
4. All of the above

3-42. The Selected Identification Feature (SIF) provides which of the following improvements to the IFF system?

1. Increased reply code totals
2. A "select single code only" feature
3. Both 1 and 2 above

3-43. In a typical IFF/SIF system, what total number of codes can be selected in Mode 3/A?

1. 32
2. 4096
3. 1024
4. 4

3-44. Which of the following modes are used by maintenance for ground testing when RAD TEST is selected?

1. 1, 2
2. 2, 3A
3. 3/A, 4
4. C, 4

3-45. Mode 4 codes are placed in the transponder by which, if any, of the following means?

1. Electrically
2. Mechanically
3. Hydraulically
4. None of the above

3-46. In a typical IFF/SIF system, where do you set the codes for Mode 2?

1. On the interrogator
2. On the control box
3. On the transponder

3-47. What is the frequency of transmission of the transponder?

1. 1090 MHz
2. 1030 MHz
3. 1120 MHz
4. 1060 MHz

3-48. When the transponder processes a Mode 1 challenge, a pulse train is transmitted containing a total of how many framing pulses?

1. 1
2. 2
3. 3
4. 4

3-49. Which reply codes are set by use of the control dials on the control box using the right-hand dial?

1. A reply pulses
2. B reply pulses
3. C mode
4. 3/A mode

QUESTION 3-50 IS TO BE JUDGED TRUE OR FALSE.

3-50. Mode C function is often referred to as AIMS, which is an acronym for Altitude Information Monitoring System.

1. True
2. False

3-51. In Mode 1, the reply pulse train containing the code is transmitted how many times for each interrogation pulse?

1. 1
2. 2
3. 3
4. 4

3-52. The emergency mode of operation can be controlled by which of the following devices?

1. Master switch
2. Seat override
3. Canopy override
4. All of the above

3-53. In a typical IFF/SIF system, the X-pulse is restricted to which of the following uses?

1. Emergencies
2. Timing
3. Helicopters
4. Drones

Assignment 4

Electronic Countermeasures (ECM); Support Equipment (SE)

Textbook Assignment: pages 4-1 through 5-21

Learning Objective: Describe the purpose and basic operation of a typical ECM configuration.

4-1. ECM equipment is used in the Navy today for which of the following purposes?

1. Detect and analyze
2. Locate and degrade
3. Both 1 and 2 above
4. Capture and destroy

4-2. Knowledge of type of scan, beamwidth, and pulsewidth of the detected signal is important in generating countermeasures against what equipment?

1. Navigation
2. Radar
3. Communications

4-3. What is the first characteristic to be determined when beginning a jamming operation?

1. The exact location of the system
2. The type of modulation used
3. The carrier frequency
4. The type of antenna used

4-4. If a signal is high frequency, its platform is more likely to be a/an __(a)__; if a signal is lower frequency, its platform is more likely to be a/an __(b)__ .

1. (a) aircraft
   (b) submarine
2. (a) ship
   (b) aircraft
3. (a) shore station
   (b) ship
4. (a) submarine
   (b) ship

4-5. What characteristic determines the maximum range of a radar set?

1. Power rating
2. PRF
3. Wavelength
4. Carrier frequency

4-6. A narrow pulse would indicate which of the following radars?

1. Long-range
2. Airborne in search mode
3. Early-warning
4. Fire-control

4-7. Of the following types of antenna scan, which is normally used for fire-control radar?

1. Lobe switching
2. Sector
3. Conical
4. Spiral

Learning Objective: Describe the basic operation of a typical passive ECM set.

4-8. Passive ECM operation is used for which of the following functions in regard to suspected hostile signals?

1. To detect
2. To locate
3. To analyze
4. All of the above

IN ANSWERING QUESTION 4-9, REFER TO FIGURE 4-1 OF THE TEXT.

4-9. The system uses antennas which are of which of the following types?

1. Omnidirectional
2. Nonpolarized
3. Rotatable
4. All of the above

TO ANSWER QUESTIONS 4-10 THROUGH 4-12, ASSOCIATE THE SECTION OF A ROTATING DF ANTENNA LISTED IN COLUMN A WITH ITS FUNCTION LISTED IN COLUMN B. RESPONSES MAY BE USED TWICE.

	A. ANTENNA		B. FUNCTION
4-10.	Narrow-beam antenna and reflector	1.	Determines the polarization of a received signal
4-11.	Horizontally polarized broadband antenna	2.	Receives a signal passing through the field of the radiated signal
4-12.	Vertically polarized broadband antenna	3.	Determines the PRF of a received signal
		4.	Determines the PRT of a received signal

4-13. A complete set of antennas for any one PECM receiver covers a maximum of how many degrees around the aircraft?

1. 60°
2. 120°
3. 180°
4. 360°

QUESTION 4-14 IS TO BE JUDGED TRUE OR FALSE.

4-14. PECM receivers have typical superheterodyne receiver circuits, each designed for coverage of a wide range of frequencies.

1. True
2. False

4-15. The IF output is fed to an IF stagger-tuned preamplifier. The purpose of this stagger-tuning is to obtain

1. maximum amplification
2. unity amplification
3. broad bandpass
4. narrow bandpass

IN ANSWERING QUESTION 4-16, REFER TO FIGURE 4-6 OF THE TEXT.

4-16. The output of the preamps in the figure goes to an impedance matching network. What is the purpose of the impedance matching network?

1. Optimum coupling
2. Feedback coupling
3. Isolation

4-17. Which of the following is/are the purpose(s) of the azimuth encoder unit?

1. Develop a quadrant-locator signal
2. Convert received analog into digital
3. Feed required antenna signals to the computer
4. All of the above

IN ANSWERING QUESTIONS 4-18 AND 4-19, REFER TO FIGURE 4-9 OF THE TEXT.

4-18. The output of Z3 is a sector containing which range of minimum and maximum degrees?

1. 270° - 360°
2. 180° - 270°
3. 90° - 180°
4. 0° - 90°

4-19. Each AND circuit represents what size sector?

1. 45° area
2. 90° area
3. 180° area
4. 360° area

4-20. The concept of going from one IF to a lower IF is called "double conversion." The purpose of double conversion is to produce an IF in which it is easier to do which of the following processes?

1. Filter
2. Demodulate
3. Amplify
4. Both 3 and 4 above

4-21. Which of the following equipments are basically used as PECM indicators?

1. Panoramic adapters
2. Pulse analyzers
3. Digital display indicators
4. All of the above

4-22. What are the two modes of operation of a typical panoramic/DF indicator?

1. Horizontal sweep and rotating PPI
2. Horizontal and vertical
3. Vertical and rotating PPI
4. Vertical and fixed

4-23. In the DF mode of operation the scope's effectiveness is dependent upon what factor?

1. Calibration techniques used
2. The size of the scope
3. The expertise of the operator
4. Narrow bandpass input

4-24. In the typical multi-sweep panoramic indicator talked about in the text, how many sweeps indicate the entire frequency spectrum covered by the PECM system?

1. 5
2. 2
3. 3
4. 10

Learning Objective: Describe the basic theory of a typical defensive ECM set.

QUESTION 4-25 IS TO BE JUDGED TRUE OR FALSE.

4-25. There are two basic categories of DECM equipment: electronic and nonelectronic.

1. True
2. False

4-26. Which of the following is/are the basic purposes of electronic DECM equipment?

1. To receive a threat radar signal
2. To inject false information
3. To retransmit a false signal
4. All of the above

4-27. Which, if any, of the following is the purpose of chaff in nonelectronic DECM operation?

1. To damage search radar
2. To create multiple targets
3. To transmit erroneous signals
4. None of the above

Learning Objective: Describe the basic operation of a typical active ECM set.

4-28. Active ECM is a term given to ECM electronic equipment which is designed to jam which of the following equipment?

1. Communications
2. Navigation
3. Radar
4. All of the above

TO ANSWER QUESTIONS 4-29 THROUGH 4-31, ASSOCIATE THE TYPE OF COUNTERMEASURE GIVEN IN COLUMN B WITH THE FUNCTION LISTED IN COLUMN A. EACH ANSWER IS TO BE USED ONLY ONCE, AND NOT ALL ANSWERS ARE USED.

	A. FUNCTION	B. ECM TYPE
4-29.	Creates high-powered noise to over drive the hostile receiver	1. Electronic DECM
4-30.	Reflects signals to present false targets	2. PECM
		3. Active ECM
4-31.	Delays the received hostile pulse, then retransmits with increased power	4. Chaff

Learning Objective: State the general practices and precautions to be observed when using support equipment and related systems.

4-32. When there is a loss of generator power, what is the primary purpose of an aircraft battery?

1. To start the engines
2. To operate specific instruments and radios
3. To maintain power for controls
4. To apply power to emergency warning systems

4-33. Running aircraft engines to provide electrical power is poor practice for which of the following reasons?

1. Danger from turning propellers
2. Danger from jet intake and exhaust blast
3. Expense of operating high powered engines
4. All of the above

4-34. When you are working on aircraft, which of the following manuals tells you the recommended power plant for that particular type aircraft?

1. Aircraft statistical data
2. Illustrated Parts Manual
3. Maintenance Instruction Manual
4. 4790.2 series

4-35. An SE operator's license is required of which of the following personnel?

1. All who operate SE
2. All who are CDIs
3. All shop supervisors
4. All crew leaders

Learning Objective: Describe the four categories of MEPPs, and the typical SE used in the Navy today.

4-36. Which, if any, of the following prefixes identifies a piece of SE that gives ac output power only?

1. NA
2. NB
3. NC
4. None of the above

TO ANSWER QUESTIONS 4-37 THROUGH 4-39, SELECT FROM COLUMN B THE TYPE OF OUTPUT POWER SUPPLIED BY THE EQUIPMENT LISTED IN COLUMN A. RESPONSES MAY BE USED MORE THAN ONCE.

	A. EQUIPMENT	B. TYPE OF POWER
4-37.	NC-2A	1. DC only
4-38.	NC-7C	2. AC only
4-39.	NC-8A	3. AC and DC

4-40. In respect to helicopters, which of the following is a purpose of the NC-10B?

1. Servicing
2. Starting
3. Maintenance
4. Each of the above

4-41. The NC-10B is self-propelled by what means?

1. Two electrical wheel motors
2. Two hydraulic wheel motors
3. One multipurpose diesel engine
4. One V-8 gasoline engine

4-42. From what source does the NC-12A obtain its dc voltage?

1. A dc generator
2. A brushless exciter
3. An ac generator
4. An external dc hookup

4-43. The self-contained RCPT-105 provides us with which of the following requirements?

1. Compressed air for engine starts
2. Ac/dc electrical power
3. Conditioned air for cooling
4. All of the above

Learning Objective: Describe the characteristics of mobile motor-generator sets.

4-44. Differing from MEPPs, the mobile motor-generator sets have which of the following characteristics?

1. Require an external source of electrical power
2. Operate only on diesel fuel
3. Used only on jet aircraft
4. Operate only with NC-2A

4-45. The MMG-2 and the MMG RX-400 provide what type(s) of output power?

1. Dc
2. Ac
3. Ac/Dc

Learning Objective: Describe deckedge power and FLEDs equipment and their uses.

4-46. What servicing and starting power is available from the deckedge power system aboard an aircraft carrier?

1. 400 Hz, 3-phase ac and 28 V dc
2. 120 Hz, 3-phase ac and 110 V dc
3. 1200 Hz, 6-phase ac and 28 V dc
4. 60 Hz, 3-phase ac and 28 V dc

4-47. What is the purpose of the rectangular and oval plugs from the dc service outlet box of deckedge power?

1. Oval for servicing; rectangular for starting
2. Rectangular for servicing; oval for starting
3. Both are interchangeable for either usage
4. Both are used for servicing of different aircraft

4-48. The FLEDS receives its output power from what source?

1. Deckedge power, flight deck
2. Deckedge power, hangar deck
3. Mobile electrical power plant
4. Underground power lines

Learning Objective: Describe the characteristics and uses of SE air conditioners, tractors, and towing equipment.

4-49. The NR-10 air conditioner differs from the NR-5C in that the NR-10 has which of the following characteristics?

1. It is mobile
2. It is trailer mounted
3. It is diesel powered

4-50. Of the A/S 32, TA-18, and TA-75 A/B tractors, which one is used to tow aircraft with gross weights up to 75,000 pounds?

1. A/S 32
2. TA-18
3. TA-75 A/B

Learning Objective: Describe the characteristics and uses of tiedowns, workstands, and trucks.

4-51. What is the rated working capacity of the TD-1A all-purpose tiedown?

1. 4,200 pounds
2. 6,850 pounds
3. 10,000 pounds
4. 16,000 pounds

4-52. What is the maximum height to which the B-4A workstand may be raised?

1. 7 feet
2. 12 feet
3. 3 feet
4. 15 feet

4-53. What is the maximum permitted hauling weight of the P-36 airfield maintenance truck?

1. 2,400 pounds
2. 2,800 pounds
3. 3,200 pounds
4. 3,600 pounds

Learning Objective: Describe general safety practices which should be observed when you are working with support equipment.

4-54. Who has the responsibility to maintain safe working conditions while personnel are working with and around support equipment?

1. Maintenance officer
2. Maintenance chief
3. Shop supervisor
4. Each individual

4-55. Which of the following rules is/are of prime concern when SE is operated aboard an aircraft carrier?

1. Set the handbrake or choke it
2. When it is not in use, tie it down
3. Keep equipment clean at all times
4. All of the above

Assignment 5

Reflectometry Test Sets; Magnetic Recorders

Textbook Assignment: pages 6-1 through 7-14

Learning Objective: Describe Time-Domain Reflectometry basics, the loads used, and the results obtained.

5-1. Intermediate maintenance technicians may use reflectometry for which of the following purpose(s)?

1. To verify cable connectors
2. To determine test cable impedances
3. To troubleshoot test equipment
4. All of the above

5-2. TDR test sets accomplish their designed function by which of the following means?

1. Measuring total resistance
2. Monitoring reflected waveforms
3. Measuring reflected impedance
4. Monitoring total impedance

5-3. If there were a fault in a transmission line, how would it be displayed on a CRT?

1. As a positive voltage
2. As a negative voltage
3. As a fast-rising voltage
4. All of the above

5-4. In time-domain reflectometry, the nature of the impedance variation in the system under test is determined by comparing reflected and incident signals as to which of the following characteristics?

1. Duration
2. Shape
3. Magnitude
4. All of the above

5-5. If a transmission line is terminated in its characteristic impedance, the signal on the CRT will have which of the following characteristics?

1. It will be in phase
2. It will be out of phase
3. Either 1 or 2 can be correct, according to the conditions
4. It will remain flat

5-6. The practice of separating the system and the TDR test set with an 8-inch cable is to prevent the occurrence of which of the following conditions?

1. Overshoot observed on the CRT
2. Ringing observed on the CRT
3. Both 1 and 2 above
4. Impedance matching

5-7. Of the waveforms displayed in figure 6-3, which one appears inductive and shorted?

1. A
2. B
3. C
4. D

5-8. Which of the following is the limiting factor in locating discontinuities which are closely spaced?

1. Transmission line length
2. System rise time
3. Reactive impedance response

5-9. The maximum observable line length of a system under test is a function of what characteristic?

1. The repetition rate
2. The dielectric of the line
3. The impedance of the line
4. The test set capabilities

5-10. The increasing slope displayed is caused by what factor?

1. A capacitive discharge
2. An inductive charge
3. An increasing series resistance
4. A decreasing series resistance

Learning Objective: Describe Frequency-Domain Reflectometry basics and the results obtained.

5-11. Compared to a TDR set, an FDR set has which of the following advantages?

1. Checks cables of greater length
2. Makes analysis at actual operating frequencies
3. Checks cables of any type dielectric material
4. All of the above

5-12. Comparison of each measured signal with the incident power of the RF oscillator gives a true graph of performance of which of the following relationships?

1. The dB versus the frequency
2. The resistance versus the reactance
3. The impedance versus the resistance
4. The frequency versus the reactance

5-13. To determine cable length or fault location which of the following equipment must be used with the FDR test set?

1. Waveguide or coaxial "tee"
2. Calibration cable
3. Both 1 and 2 above
4. Oscilloscope

QUESTION 5-14 IS TO BE JUDGED TRUE OR FALSE.

5-14. Amplitude "ripples" on the CRT result from the summing of the incident and reflected signals.

1. True
2. False

5-15. In the formula $D = \frac{492KN}{\Delta F}$, used to find distance to a fault, ΔF represents what quantity?

1. Sweep width
2. Oscillator frequency
3. Number of ripples
4. Transmission-line frequency

5-16. The AN/USM-402(V) test set has which of the following power requirements for proper operation?

1. 115 V ac
2. 230 V ac
3. Either 1 or 2
4. 28 V dc

IN ANSWERING QUESTIONS 5-17 THROUGH 5-20, ASSOCIATE THE TYPE OF REFLECTOMETRY IN COLUMN B WITH THE CAPABILITIES GIVEN IN COLUMN A. TYPES MAY BE USED MORE THAN ONCE.

	A. CAPABILITIES	B. REFLECTOMETRY TYPES
5-17.	Unable to see through low-pass or band-pass filters	1. TDR
		2. FDR
5-18.	Works in waveguides and band-limited systems	
5-19.	Requires a transmission line that passes the whole spectrum	
5-20.	Detects all discontinuities	

Learning Objective: Describe components and operating principles of magnetic recorders, including the recording, erasing, and playback processes.

5-21. Magnetic recorders are well suited for use in ASW systems for which of the following reasons?

1. They are easily obtainable because they are used extensively throughout the Navy
2. They are cost-effective because they are stocked in large quantities in the Navy supply system
3. They can store large amounts of data in a small area
4. Their media can be reused many times to store electronic data

QUESTION 5-22 IS TO BE JUDGED TRUE OR FALSE.

5-22. The different types of magnetic record/playback equipment operate by rearranging the particles of a magnetic medium and/or by detecting and acting in accordance with the new arrangement.

1. True
2. False

5-23. Besides recording, what basic processes are involved in the operation of a magnetic recorder?

1. Reproducing and amplifying
2. Erasing and coding
3. Erasing and reproducing
4. Amplifying and coding

5-24. As the recording medium passes through the magnetic field of the recording head, the particles of permeable material on the medium are aligned according to what factors?

1. The instantaneous speed and direction of the medium
2. The instantaneous direction and magnitude of the magnetic field
3. The average speed and direction of the medium

5-25. When a split-ring electromagnetic recording head is used in a recorder, information is recorded on the medium as it passes over what part of the head?

1. The magnetic ring
2. The ring coil
3. The ring gap
4. The power supply

QUESTION 5-26 IS TO BE JUDGED TRUE OR FALSE.

5-26. Analog recording techniques are used mainly for recording audio signals that are normally listened to by ear.

1. True
2. False

5-27. Hysteresis in the recording head magnet can cause amplitude distortion to the recorded signal. Which of the following bias signals is mixed with the signal being recorded to reduce the distortion?

1. A high-frequency variable-amplitude signal
2. A high-frequency constant-amplitude signal
3. A low-frequency variable-amplitude signal
4. A low-frequency constant-amplitude signal

5-28. Increasing the speed of the tape motion across the head produces which, if any, of the following results?

1. Increased usable frequency range
2. Decreased usable frequency range
3. Increased hysteresis loss
4. It has no effect

5-29. The flux pattern recorded on magnetic tape is determined by which of the following factors?

1. The magnitude and direction of the recorded signal
2. The strength of the recording head magnet
3. The reluctance of the recording tape
4. The width of gap in the recording head

5-30. In the playback process, the signal to be amplified for reproduction of the data stored on the tape comes from which of the following components?

1. Reproducer amplifier
2. Reproducer coil
3. Playback amplifier
4. Playback speaker

5-31. In playback, which of the following factors cause(s) voltage across the coil to increase?

1. Tape speed
2. Increased frequency
3. Both 1 and 2 above

QUESTION 5-32 IS TO BE JUDGED TRUE OR FALSE.

5-32. In playback, if tape speed and the width of the gap are constant, the output voltage will continue to increase as long as the frequency continues to increase.

1. True
2. False

5-33. An equalizer stage in a magnetic tape recorder-reproducer serves to compensate for losses in the amplitude of which of the following signals?

1. Low-frequency
2. Middle-frequency
3. High-frequency
4. Noise-frequency

5-34. An increase in recording fidelity will result from ______(a)______ (an increase, a decrease) in tape speed with resultant ______(b)______ (extension, compression) of magnetic fields along the tape.

1. (a) An increase (b) extension
2. (a) An increase (b) compression
3. (a) A decrease (b) extension
4. (a) A decrease (b) compression

5-35. The fidelity of recording and reproduction by a magnetic tape recorder is affected by the quality of electronic and mechanical components and by which of the following factors?

1. Tape speed
2. Tape coating materials
3. Recording techniques
4. Each of the above

5-36. Previously recorded tapes are often erased for which of the following reasons?

1. To avoid compromise of the recorded information
2. To allow the tape to be efficiently used again
3. To prevent distortion of information previously recorded on the tape
4. To increase the permeability of the tape

5-37. In a recorder-reproducer set, the gap width of the erase head normally has which of the following relationships to other head gaps?

1. The same as the record head gap
2. Twice the record head gap
3. The same as the playback head gap
4. Twice the playback head gap

5-38. The precise number of heads stacked together in a head assembly is dependent upon which of the following factors?

1. The type of bias used, the track width, and the length of the tape
2. The type of bias and the track width only
3. The type of head used, the track arrangement, and the width of the tape
4. The length of the tape and the amplitude of the recording signal

5-39. Normally, which of the following head stack arrangements would be used for recording and reproducing in computer applications where track-to-track crosstalk is NOT an important factor?

1. Staggered
2. Interleaved
3. In-line

5-40. Tapes recorded on a 7-head, in-line arrangement must be reproduced by a recorder with which of the following head arrangements?

1. 7-head, in-line
2. 7-head, interleaved
3. 14-head, in-line
4. 14-head, interleaved

Learning Objective: State the purposes of and correct procedures for cleaning and demagnetizing magnetic tape recorder heads.

5-41. Magnetic recording heads should be cleaned periodically for which of the following reasons?

1. To increase head efficiency and life
2. To increase head magnetic field intensity
3. To decrease head reluctance and magnetization

5-42. The degaussing process is used for which of the following reasons?

1. To diminish noise at high frequencies
2. To eliminate residual magnetization of heads
3. To restore neutrality to heads
4. All of the above

5-43. Each time a ______(a)______ (cleaning, degaussing) is done ______(b)______ (cleaning, degaussing) should be accomplished first.

1. (a) Cleaning (b) degaussing
2. (a) Degaussing (b) cleaning

5-44. When a recorder-reproducer head is being demagnetized, the degausser should be placed no closer than what distance from the head?

1. 1/4 inch
2. 1/16 inch
3. 1/32 inch
4. 1/8 inch

QUESTION 5-45 IS TO BE JUDGED TRUE OR FALSE.

5-45. Degaussing should be performed by moving the degausser in a back-and-forth motion above the gap, and then in a circular motion as it is removed from the area of the head.

1. True
2. False

Learning Objective: Describe the mechanical operating components of a magnetic tape recorder.

5-46. The mechanical section of a magnetic tape recorder handles the tape during which of the following functions?

1. During playback only
2. During rewind only
3. During record and rewind only
4. During record, rewind, and playback

Learning Objective: Describe the process of digital recording and explain how it differs from analog recording.

QUESTION 5-47 IS TO BE JUDGED TRUE OR FALSE.

5-47. The fundamental difference between analog and digital recording is the method and degree of magnetization.

1. True
2. False

5-48. In digital systems, where is the data contained?

1. In a varying current
2. In flux transitions
3. In constant FM voltages

5-49. The carrying of information in the flux reversals has which of the following advantages?

1. No critical bias levels to maintain
2. No record levels to maintain
3. No adjustments in the recording electronics needed
4. All of the above

5-50. In digital recording in the write mode, which of the following basic techniques is/are used?

1. Return-to-zero
2. Return-to-bias
3. Non-return-to-zero
4. All of the above

5-51. In a return-to-zero system, the magnetic field of the record head returns to zero flux when which of the following conditions exists?

1. A 1 or 0 is present
2. A 1 or 0 is not present

QUESTION 5-52 IS TO BE JUDGED TRUE OR FALSE.

5-52. In a return-to-bias recording system, only 0's generate flux changes.

1. True
2. False

5-53. The erase process for digital recording is accomplished by applying ___(a)___ current; the
(ac, dc)
recording medium is saturated in ___(b)___ direction(s).
(one, both)

1. (a) ac (b) one
2. (a) ac (b) both
3. (a) dc (b) one
4. (a) dc (b) both

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PRINT OR TYPE

Aviation Electronics Technician 3 & 2, Part 2
NAVEDTRA 10317-F

NAME ______________________________ ADDRESS ______________________________
Last First Middle Street/Ship/Unit/Division, etc.
____
City or FPO State Zip

RANK/RATE ________ SOC. SEC. NO. ______________________ DESIGNATOR ________ ASSIGNMENT NO. ________

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PRINT OR TYPE

Aviation Electronics Technician 3 & 2, Part 2
NAVEDTRA 10317-F

NAME ______________________________ **ADDRESS** ______________________________
Last First Middle Street/Ship/Unit/Division, etc.

____
City or FPO State Zip

RANK/RATE ________ **SOC. SEC. NO.** ____________________ **DESIGNATOR** ________ **ASSIGNMENT NO.** ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ____________________ DATE MAILED ____________

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PRINT OR TYPE

Aviation Electronics Technician 3 & 2, Part 2
NAVEDTRA 10317-F

NAME ______________________________ ADDRESS ______________________________
Last First Middle Street/Ship/Unit/Division, etc.

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City or FPO State Zip

RANK/RATE ________ SOC. SEC. NO. ______________________ DESIGNATOR ________ ASSIGNMENT NO. ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ________________ DATE MAILED ________

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PRINT OR TYPE

Aviation Electronics Technician 3 & 2, Part 2
NAVEDTRA 10317-F

NAME ______________________________ ADDRESS ______________________________
Last First Middle Street/Ship/Unit/Division, etc.

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